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Evaluation of Fish Movements, Migration Patterns, and Population Abundance with Streamwidth PIT Tag Interrogation Systems

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Bonneville Power Administration Completion Report for
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Evaluation of fish movements, migration patterns, and population abundance with Streamwidth PIT tag Interrogation systems

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Executive Summary

Two remote Streamwidth PIT tag Interrogation systems (SPIs) were operated continuously for over one year to test the feasibility of these systems for generating movement, migration, survival and smolt production estimates for salmonids. A total of 1,588 juvenile (< 100 mm FL) naturally produced salmonids (7 coho salmon, 482 cutthroat trout, and 1,099 steelhead) were PIT tagged above the upstream-most SPI (9 sites approximately 1 linear km each) in Fall 2001. Age at tagging for wild caught cutthroat and steelhead was 1 year. SPIs were operating before any PIT tagged fish were released in the creek. Over 390,000 detections were recorded from October 2001 to 31 July 2002. Efficiencies were site dependent, but overall detection efficiency for the creek was 97% with 95% confidence intervals of 91 – 100%. PIT tag detection efficiency ranged from 55–100 % depending on the SPI and varied throughout the year with average efficiencies of 73 % and 89 %. SPI efficiency of PIT tag detection was not completely dependent on electronics noise levels or environmental conditions. Fish from all tagging locations were detected at the SPIs. Steelhead and cutthroat trout were primarily detected moving in the Spring (April – June) coincident with the anticipated smolt migration. Steelhead were also detected moving past SPIs at lower numbers in the Fall and Winter. Travel time between SPIs (downstream movement) was highly dependent on time of year. Travel time in the Spring was significantly faster (34.4 ± 7.0 hours) for all species than during any other time of year (763.1 ± 267.0 hours). Steelhead and cutthroat migrating in the Spring were the same age as those that did not migrate in the Spring. Peak of steelhead migration recorded at the two SPIs was 5/11 and 5/12 and the peak in the screw trap was recorded on 5/17. Steelhead smolt production estimates using SPIs (3,802 with 95% confidence intervals of 3,440 - 4,245) was similar to those using more standard screw trap methods (approximately 5,400). All species used the faster-moving/deeper section of the creek at both SPIs. A backpack PIT tag detector was also developed and used as another remote "recapture" for additional accuracy in estimating population survival and recapture probability. This unit was used at an approximate efficiency of 24% to survey the creek after the Spring migration. Twenty-five individual fish were re-located. All PIT tag data were used to calculate survival and recapture probabilities using the Cormack-Jolly-Seber population model. Survival for steelhead was high and recapture probability depended greatly on season. Probability of recapture was highest in Spring (29.5%) and relatively low in all other seasons (< 7% in Fall, Winter, and Summer). Wild steelhead PIT tagged in the field and returned to the laboratory had a tag retention rate of 97.6%. A laboratory study was designed to determine the effects of 3-sized PIT tags (12 mm, 20 mm, and 23 mm) on survival and growth of individuals. Survival from surgical implantation of 23 mm PIT tags was > 98% for fish (coho salmon and steelhead). Retention of 23 mm PIT tags was 100% for coho salmon and 89% for steelhead. For both coho and steelhead, growth rates during the first month were affected by tagging, but by the end of 2 months growth effects equalized for all tag sizes. Life history characteristics quantified with SPI techniques are comparable to standard techniques. For example, peaks of Spring migration for steelhead and cutthroat were amazingly similar to those reported from the screw trap. These techniques will enable application of less laborious methods which are more accurate at estimating life history parameters.

Introduction and background

Results from this project are relevant to objectives identified in multiple sections of the 2000 Northwest Power Planning Council Fish and Wildlife Program. According to the Basinwide Biological Objectives (Section III C 2) efforts must be made to describe responses of populations to habitat conditions in terms of abundance and life history diversity. Life history diversity was documented for three species of salmonids in this study, including resident (III C 2a3) and anadromous fish that are considered to be at "depressed levels". The measurable and quantitative data presented in this report are also available to the public through a previously established database (PTAGIS, PSMFC) used throughout the Columbia River Basin (meeting the objectives of Section III D 9).

Baseline freshwater life history information was collected to begin to determine population status of native species (Section III C 2a1) and resident fish (Section III C 2a3, cutthroat trout). There is a growing interest in data collection for managing wild and naturally spawning populations. The Wild and Naturally Spawning Population Policy states that management measures must be developed to maintain life history, morphology and genetic characteristics of wild and naturally spawning populations. Little is know concerning the life history characteristics of cutthroat trout, native steelhead trout or coho salmon in Abernathy Creek. Washington Department of Fish and Wildlife (WDFW) has only recently started to collect information at a smolt trap operated at the mouth of Abernathy Creek in the Spring. Total smolt production estimates depend on trap efficiencies between 15 and 30 %. The PIT techniques described in this report result in smkolt production estimates that depend on PIT detection efficiencies of 97%. Important aspects of the freshwater portion of coho salmon, steelhead and cutthroat trout were collected in this study.

Monitoring and evaluation of freshwater life history information was collected to improve management and conservation of wild and naturally spawning populations (identified as a need in Section III D 4). Baseline information collected and reported here (e.g., time of migration, age at migration, winter survival) will be compared to post-manipulation situations to assess life history changes associated with modifications in hydropower operation (Section III D 6) or habitat manipulations (Seciton III C 2). Specifically, Cowlitz County is in the process of purchasing Conservation Easements on Abernathy Creek. How the planting of riparian areas effects salmonid populations in the future can be monitored with the methods initiated in this study. Under ESA Section 7 when conducting analyses of habitat-altering actions the status and biological requirements of the potentially impacted species and the effects of the action on species must be determined. The specific effects on Abernathy Creek will be monitored and evaluated using these methodologies. Further, the relative effectiveness of these comparisons can be applied to other tributaries of the Columbia River Basin. Of particular interest in many cases is the effect on juvenile survival, which is directly quantifiable using these methods.

Section 9 of the NMFS 2000 FCRPS Biological Opinion identifies the need for novel fish detection and tagging techniques for use in long-term research and monitoring and evaluation efforts (RPA 193). The techniques described in this report (new and innovative PIT tag technology) have enormous potential for wide-ranging applicability throughout the Columbia River Basin. Also, RPA 188 states that studies of PIT tagged wild stocks from the lower river streams need to be conducted to constrast stock productivity and hydrosystem effects. This is addressed for three populations of salmonids in a tributary of the lower Columbia River.

This report details newly developed remote monitoring tools. These tools were used to assess salmonid populations in Abernathy Creek, Longview, WA. The first objective of the study was to validate PIT tag systems for small stream applications (Section I. Technology Development). The second objective was to acquire baseline information on the life history characteristics for three species of salmonids (Section II. Biological Validation). The final objective was to verify the effects of PIT tags on individual fish in order to validate objectives 1 and 2 (Section III. Tagging Effects).

Evaluation of fish movements, migration patterns, and population abundance with Streamwidth PIT tag Interrogation systems: I. Technology Development

Abstract:

Two remote Streamwidth PIT tag Interrogation systems (SPIs) were established in Abernathy Creek to test the feasibility of these systems for generating movement, migration, survival and smolt production estimates for salmonids. SPIs were installed and operating before any PIT tagged fish were released in the creek. Systems were designed to report all detected PIT tag codes with a time stamp to a regional database. When used in combination, the overall creek detection efficiency was 97% with 95% confidence intervals of 91 – 100%. SPI efficiency of 23 mm PIT tag detection ranged from 55–100 %. Efficiencies were site dependent, where one SPI averaged 73% and another averaged 89%. SPI efficiency of PIT tag detection was not completely dependent on electronics noise levels or environmental conditions. A backpack PIT tag detector was also developed and tested for efficiency of PIT tag detection. The unit had an approximate efficiency of 24% when operating in the field at a pace that enabled full stream (8 km) coverage in a relatively short period of time (2 weeks). The relatively high efficiency and predictability of detecting PIT tags with SPIs is likely to allow more accurate estimates of fish movement, migration patterns and population abundance than has been available previously.

Introduction:

Over the last decade Passive Integrated Transponder (PIT) technology has facilitated affordable mass marking. This technology has been used primarily to monitor migration through small orifices, especially at dams (Prentice et al. 1990 a&b; Giorgi et al. 1997). Recently PIT tags have been used in field applications for individual marking of many fish species. In most instances fish are PIT tagged and physically recaptured to gain individual information on life history characteristics (e.g. Hilderbrand and Kershner 2000), for use in individually-based models of population dynamics (van Winkle et al. 1993; Juanes et al. 2000), or to gain insight concerning variability in individual behaviors (Bell et al. 2001).

The use of long-range PIT tag technology (using 23 mm or larger PIT tags) was first applied to monitor movements of fish through large fishway orifices (Castro-Santos et al. 1996). Morhardt et al. (2000) first suggested the use of pass-through PIT tag antennas (for detection of 23 mm tags) for streams up to 4 m across because of the increased detection range of PIT tags antennas oriented upright (pass-through) versus when they were laid flat on a stream bed (flat plate design: Armstrong et al. 1996). Zydlewski et al. (2001) were the first to apply the pass-through design in a natural stream 8 m in cross section and achieved detection efficiencies averaging 93%. Innovations in PIT tag technology may enable remote detections of PIT tags to accurately record life history characteristics such as smolt number, relative abundance, survival, habitat use, movements, population size, and recapture probabilities.

Although these monitoring methods have been applied successfully in small streams using half duplex (e.g. Zydlewski et al. 2001, Texas Instruments) systems they have not been demonstrated with full duplex (Destron Fearing) systems. The objective of this study was to validate full duplex PIT tag systems for small stream applications.

Methods:

Stationary System Construction

In August 2001 two Stream-width PIT Interrogation systems (SPIs) were installed on Abernathy Creek. The systems incorporated full-duplex PIT tag technology (provided by Digital Angel Corporation/Destron Fearing). These systems were optimized for detection of 23 mm PIT tags (23 mm long, 3.4 mm wide, 0.6 g in air). Two areas were defined as adequate for installation of pass-through systems and would enable examination of downstream movements of most of the taggable salmonid populations in the creek.

SPIs were designed and constructed at two bridges, one at the Abernathy Fish Technology Center (AFTC) and one approximately 1 km downstream of AFTC (DAVIS). The width of Abernathy Creek at the AFTC bridge is 11.04 m. This location required the construction of three antennas to cover the entire width of the stream (Table 1 and Figure 1). Each antenna was energized by a FS1001A Destron Fearing AC powered transceiver. The transceivers were linked using fiber optics to a computer that ran software (MiniMon, Pacific States Marine Fisheries Commission) to continuously record date, time, and PIT code of all fish passing the SPIs. Detection data were uploaded every 12 h to the Pacific States Marine Fisheries Commission (PSMFC) PTAGIS database for later interrogation of individual fish.

The width of Abernathy Creek at the DAVIS bridge is 7.8 m. This location required the construction of two antennas to cover the entire width of the stream (Table 1 and Figure 2). Each antenna was energized by a FS1001A Destron Fearing 24 Volt DC powered transceiver. AC power was supplied to the enclosure containing the transceivers. The AC power was then converted to DC using an AC/DC converter. A ruggedized laptop computer (MicroSlate, Quebec, Canada) was located next to the transceivers to continuously record, date, time and PIT code of all fish passing the SPIs. The switching noise generated by the transformer of the computer interfered with the transceivers but when the transformer was isolated using an isolation transformer there was no further interference. Data were uploaded to the PTAGIS database every 12 h via a satellite modem (Starband).

SPI installations depended greatly on the structures to which they were attached. Structures were designed to hold 10 cm PVC structures in place during high water. Vertical structures mid-creek (appropriate for antenna dimensions, see below) were established by burying one end of a 15 cm diameter, 6 m long post into the creek substrate and securing them at the stream bottom with steel rebar or T-posts and at the top to the bridge. On each vertical structure a C-channel constructed of fiberglass was attached in order to slide each antenna into proper position. This also allowed removal of antennas.

Antennas making up SPIs were constructed with 6-strand 18 gauge ribbon cable. The cable was threaded through a 1.91 cm PVC pipe which was centered (using wood blocks) inside a 10.2 cm PVC pipe. The wires were terminated to form a continuous 6-stranded loop at one corner of the PVC structure. A set of capacitors, appropriate for the inductance of the antenna (Table 1), was soldered to one lead of the loop of wires and then the capacitors were soldered to one lead on a connector in the PVC pipe. The other wire of the loop was soldered directly to the other lead of the connector. The connector on the pipe was then attached to a cable that ran back to the Destron Fearing transceivers. Cable length was limited below 15 m to provide enough power to the antennas. Transceivers were synchronized to one another using a hard-wired synchronization cable. For more details concerning transceiver operation please consult Destron Fearing.

The electromagnetic field created by each antenna extends beyond the physical loop created by the PVC pipe structure. Therefore, the fields of adjacent antennas interfered with one another. To compensate for this, interference antennas had to overlap one another by anywhere from 20 – 38 cm depending on the physical proximity of the antennas and the length dimensions of the constructed antennas exceeded the width of the bridges.

TABLE 1. Antenna dimensions and characteristics at AFTC and DAVIS SPIs on Abernathy Creek. These units continuously detected PIT tagged fish from 1 October 2001 to present.***

Site	Antenna designation	Length m	Height m	Capacitance pF	Cable length m
AFTC	A1	3.5	1.9	3660	12
AFTC	A2	3.7	1.7	3660	9
AFTC	A3	4.5	1.3	3320	6
DAVIS	B1	4.0	1.8	3170	9
DAVIS	B2	4.0	1.7	3320	6

*** AFTC was not operational from 15 – 19 November 2001 and 26 January – 1 February 2002. DAVIS was not operational from 15 November 2001 – 26 December 2001 and 25 January 2002 – 3 March 2002.

Installation of SPIs was completed 31 August 2001. Monitoring at SPIs was initiated before any PIT tags were placed into the system (see Biological Validation of Technology section). Therefore, individual monitoring was initiated immediately after tagging.

FIGURE 1. Streamwidth PIT tag Interrogation system (SPIs) located at Abernathy Fish Technology Center (AFTC) on Abernathy Creek. (a) Antennas (wire within the PVC structures) spanning the entire streamwidth (right: A1, middle: A2, left: A3). (b) Destron Fearing transceivers energize the antennas depicted in a. Each antenna requires one transceiver.

a.

b.

FIGURE 2. Streamwidth PIT tag Interrogation system (SPIs) located 1 km downstream of AFTC (DAVIS) on Abernathy Creek. (a) Antennas (wire within PVC structures) spanning the entire streamwidth (B1 right and B2 left). (b) Destron Fearing transceivers energize the antennas depicted in a. Also shown are the ruggedized laptop, satellite modem, AC/DC converter, isolation transformer, and computer backup.

a.

b.

Stationary System Detection Efficiency

Four independent measures of SPI efficiency were established. (1) From 6 December 2001 to 29 July 2002 a tag was floated (a 23 mm PIT tag was inserted into the end of polypropylene rope) through the field of each antenna at each SPI. The rope floated at the surface of the water and was allowed to move through each antenna at the speed of the water. This test was conducted at least weekly at both the AFTC and DAVIS SPIs. (2) The AFTC SPI was evaluated by determining the number of PIT codes detected at DAVIS that were not detected at AFTC. All PIT codes entered the system upstream of AFTC and should have been detected at AFTC previous to being detected at DAVIS. (3) The DAVIS SPI was evaluated by releasing PIT tagged fish upstream of the SPI. In Spring 2002, 387 coho salmon were captured in a screw trap (for details see Section II), were PIT tagged and released upstream of DAVIS. All of these individuals were assumed to continue migrating downstream and detection at DAVIS should theoretically have been 100%. (4) Both systems were evaluated by determining the percent of previously PIT-tagged fish that were detected at the SPIs and captured in the screw trap. All fish entering the screw trap had been PIT tagged upstream of the AFTC SPI.

A measure of the effectiveness of the transceivers at the SPIs is related to the noise levels reported to the computer from the transceivers. Noise is recorded as the level of radio frequency noise in the surrounding environment that is close to the frequency (or harmonics of that frequency) that the tags and transceivers operate (134.2 kHz). Noise reports were sent to the computer from all transceiver units every 10 min. These data were continuously monitored and changed based on ambient noise conditions (e.g. operation of electric fences or other electrical equipment) as well as environmental changes around the antennas (e.g. water level, turbidity, sun light). Transceivers were adjusted (tuned) accordingly. These data were also averaged (hourly) for correlating transceiver/antenna performance with environmental condition.

Environmental Conditions

Environmental conditions measured included water temperature and water depth ($n = 294$ continuously using a Vemco temperature and depth logger), a second measure of water depth ($n = 41$, using a water staff at AFTC), and water velocity ($n = 7$). Because continuous water depth recorded by the data logger at AFTC was positively correlated with values recorded on the water staff (Pearson Correlation Coefficient, CC = 0.755, $p < 0.00001$, $n = 41$), correlations of water depth with transceiver noise and antenna detection efficiencies were conducted with depth data from the logger.

On two occasions water levels in Abernathy Creek rose rapidly and antennas were displaced from the stationary locations. On 14 November 2001, 16.6 cm of precipitation fell in a 24-h period and on 24 January 2002, 10.2 cm of precipitation fell in 24 h. The AFTC SPI was replaced on 20 November and 1 February and operated continuously from 1 September to 14 November 2001, from 20 November 2001 to 25 January 2002, and 1 February 2002 to present. The DAVIS SPI was replaced on 27 December 2001 and 4

March 2002 and operated continuously from 1 September to 14 November 2001, from 27 December 2001 to 25 January 2002, and from 4 March to present.

Backpack System

A portable (backpack) detection system was designed and constructed by Destron Fearing. A FS1001A transceiver and battery packs were enclosed in the transceiver housing and was attached to an aluminum frame backpack. An antenna wand 2 m in length with an open coil inductor loop 0.5 m diameter was attached to the end.

FIGURE 3. Backpack PIT tag detector used to unobtrusively scan all reaches of Abernathy Creek. Destron Fearing FS1001A attached to a backpack and a 50 cm square antenna coil on the end of a 2 m wand.

Efficiency of "recapturing" or detecting fish with the backpack unit was estimated at the time stream surveys were conducted. On 25 June 2002, a 52.1 m stretch of Abernathy Creek was blocked with nets and electrofished one time (from 1035 hours – 1133 hours). All fish captured on the first pass were anesthetized and interrogated for PIT tags. None of the captured fish were previously PIT tagged. Nineteen steelhead trout were large enough to be PIT tagged (> 100 mm) with 23 mm tags. Fish were randomly returned throughout the site at 1240 hours. After approximately one hour the individuals conducting standard backpack surveys of the creek were asked to scan the site with the unit (at a rate that makes moving through the entire creek feasible in two weeks time) and detect PIT tagged fish. Two individuals blindly conducted surveys of the area. Block nets were cleaned and maintained overnight and a second survey was conducted by each individual at approximately 24 h post-tagging.

Results:

Stationary System Construction

During initial SPI installations the structures at AFTC and DAVIS consisted of vertical posts attached through a weak link (a 2 x 6 board) to the associated bridge. This was precisely where the structures broke away in November. This design was modified and vertical structures were attached directly to the bridges. During the second high water event another weak link was discovered to be substrate scouring. Vertical posts were disabled from the bottom during the high flow event. After this event vertical structures were fortified by cabling the bottom of each structure to T-posts strategically located upstream.

Stationary System Detection Efficiency

Overall detection efficiencies were as high as 100%. The DAVIS site averaged above 84% and on most occasions was 100% efficient. Movement past a specific SPI is related to the overall average efficiency of the group of antennas (3 at AFTC, 2 at DAVIS). Efficiency of PIT tag detection was antenna-dependent where on any one occasion one antenna could have an efficiency of 100% while the others could be as low as 0%. During 40 efficiency tests using a neutrally buoyant tag floated through each antenna 10 times, the average (± SE) efficiency at AFTC was 78.2 ± 3.3% (A1 = 54.9 ± 6.1, A2 = 83.3 ± 4.6, A3 = 100 ± 0). During 21 similar tests conducted at DAVIS the average efficiency of detection was 95.5 ± 3.6% (B1 = 93.3 ± 5.1, B2 = 97.6 ± 2.4).

Efficiency of detection based on the number of PIT tagged fish recaptured in the screw trap in the Spring was 96%. A total of 45 fish PIT tagged in the Fall 2001 were recaptured in the screw trap. Of those, 43 were detected at AFTC and DAVIS. Thirty-one of those captured in the screw trap had been detected at AFTC (69% efficient) and 39 had been detected at DAVIS (87% efficient).

AFTC efficiency based on numbers of fish detected at DAVIS that were not detected at AFTC was 71%. Of the total number of fish detected at both sites (361), 104 were uniquely detected at DAVIS, i.e. never detected at AFTC even though they passed that site before reaching DAVIS. Therefore, AFTC missed 29% of the fish it should have detected. These detection efficiencies were the same for steelhead (total detected = 328) and cutthroat (total detected = 31) trout (95 steelhead and 9 cutthroat were not detected at AFTC but were detected at DAVIS). DAVIS efficiency based on numbers of coho salmon tagged and released above the SPI in the Spring was 84%. The SPI detected 324 of the 387 released fish.

When the two SPIs were used in combination their overall detection efficiency was 97% with 95% confidence intervals ranging from 91 – 100%. This was based on the fact that of the potential 27% of the PIT tags un-detected at AFTC 89% of those should be detected at DAVIS.

Daily reports of transceiver/antenna performance revealed that each SPI had a unique level of ambient radio frequency noise (Figures 4 and 5). Average noise levels at AFTC were generally higher than those at DAVIS. Noise levels were completely dependent on maintenance of the SPIs. In many cases there was trial and error involved in tuning the antennas to the appropriate level for the environmental conditions. Typically, as water levels rose and fell the capacitance in the transceiver needed to be adjusted (tuned).

FIGURE 4. Averaged daily noise reported from transceivers at AFTC. Note that A1 and A2 were not operational from 15 - 19 November 2001 and 26 January – 1 February 2002 due to high water, and A3 was removed on 7 June 2002 due to low water.

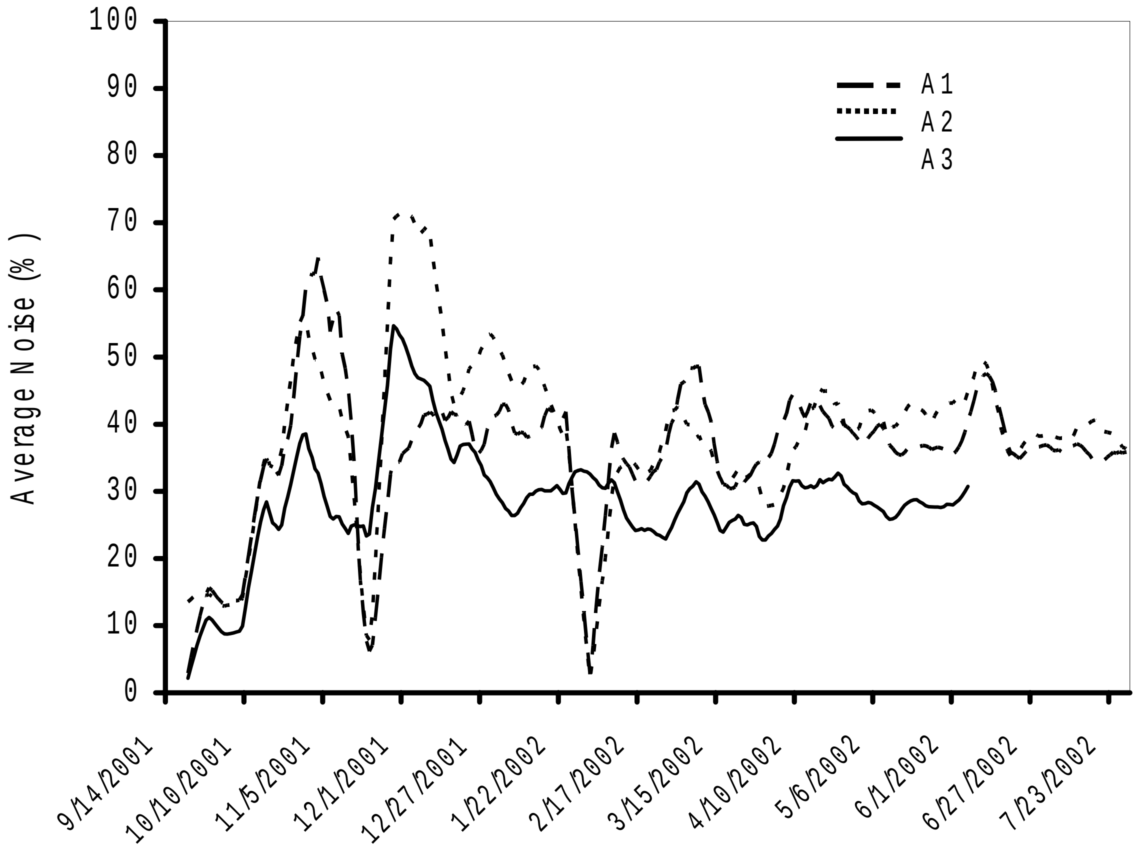
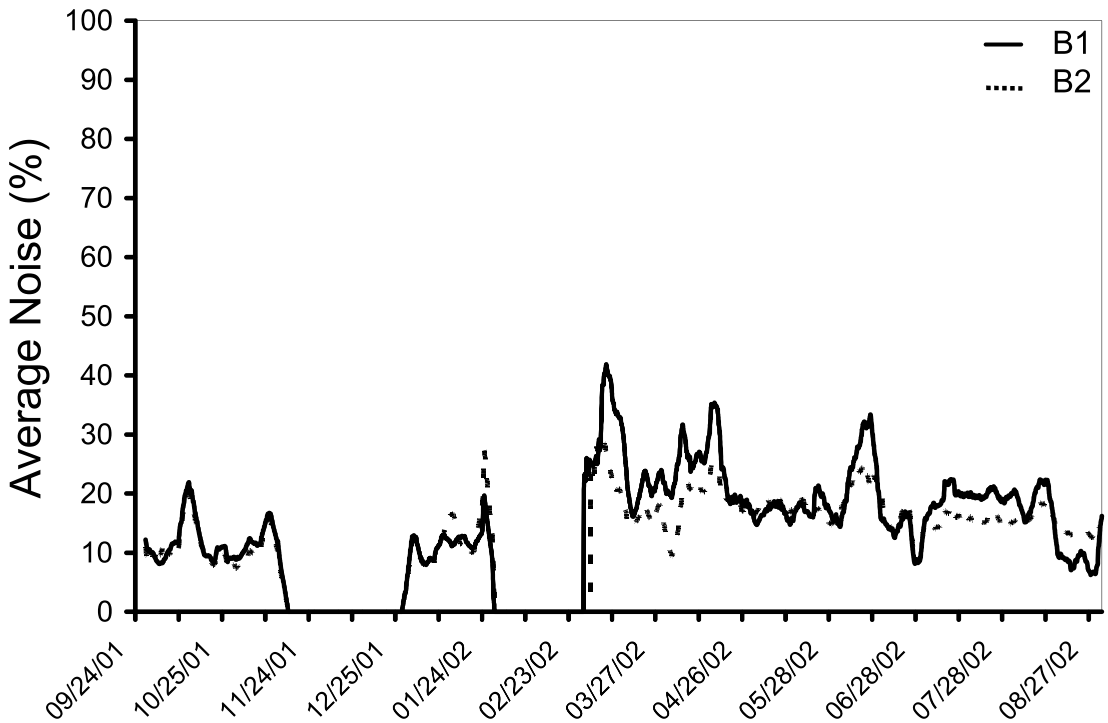


FIGURE 5. Averaged daily noise reported from transceivers at DAVIS. Note that this site was not operational from 15 November – 26 December 2001 and 25 January – 3 March 2002.



Environmental Conditions

At both AFTC and DAVIS noise levels of the SPIs were correlated with changes in water depth. Noise levels increased significantly as water levels rose at A2 (Correlation Coefficient (CC) = .162, $p = 0.006$, $n = 285$) and A3 (CC = 0.174, $p = 0.008$, $n = 232$), but not at A1 ($p=0.491$). At DAVIS noise levels decreased as water depths increased (CC = -0.258 and -0.291, $p < 0.0001$, $n =215$ for B1 and B2).

Average detection efficiencies at AFTC were not correlated with average noise levels ($p = 0.647$). However, independently A2 detection efficiency decreased as A2 noise increased (CC = -0.368, $p = 0.0196$, $n = 40$). At DAVIS overall detection efficiency decreased as noise levels increased (CC = -0.661, $p = 0.0020$, $n = 19$) but these correlations were not significant for B1 and B2 independently due to the low number of non-100% efficiency estimates ($p > 0.39$).

Average AFTC detection efficiency was not correlated with water depth ($p = 0.307$). However A1 detection efficiency decreased as water depth increased (CC = -0.398, $p = 0.0146$, $n = 40$). Water velocity was not correlated with average detection efficiency at AFTC ($p = 0.339$).

At AFTC noise levels were not correlated with water temperature ($p > 0.714$) or water velocity ($p > 0.502$). At DAVIS noise levels were negatively correlated with water temperature (CC = -0.242 and -0.156, p = 0.0003 and 0.0222, n = 217 and 215, for B1 and B2 respectively).

Average detection efficiency with the backpack unit was 24%. Scans of the 52.1 m area approximately one hour post-release were conducted in 20 (scan 1a) and 27 min (scan 1b). Scans approximately 24 hours post-release were conducted in 35 (scan 2a) and 40 min (scan 2b). During scans 1a and 1b five PIT tags were detected each time. However, only one of the five PIT tags was the same between scans (a and b). In other words, the total number of unique codes found was 9. During scans 2a and 2b four PIT tags were detected each time. Two of the four were identical and each person found two unique codes (a total of 6 unique identifications). A total of three additional unique PIT tags were identified, one of which was not PIT tagged the previous day but had been tagged on 5 October 2001 in L1 (see Section II for details).

Discussion:

Using 23 mm PIT tags enabled construction of antennas much larger than reported previously in the literature (slightly larger than those reported by Zydlewski et al. 2001). Pass-through antenna systems require a substantial amount of support to sustain them under high water conditions. This type of support is best offered in areas where streams are artificially restricted, e.g. at bridges, culverts or dams. However, down periods in this study did not gravely affect the project because both events occurred when little fish movement was occurring (See Section II).

Daily operation and therefore fish detection efficiency differed by site and changed with operator experience. Over time it became obvious that the AFTC and DAVIS sites had different ambient noise conditions that greatly affected their operation. The AFTC SPI was consistently 20-30 % noisier than the DAVIS site. This was continuously contemplated and conditions with transceivers and antennas were changed on a regular basis throughout the Fall and Winter 2001. After considerable technical manipulations it was determined that the higher noise levels at AFTC were due to general operations of the AFT Center. However, the DAVIS SPI was located immediately adjacent to an electric fence that caused intermittent noise perturbations but did not seem to affect reading efficiencies. In Spring 2002, SPIs appeared to reach what we felt were optimum conditions. For this reason, tag detection efficiencies reported were likely conservative because system operations changed over time while measures of detection were based on all time periods.

Water depth and transceiver noise levels were somewhat predictive of PIT tag detection efficiency. Detection efficiencies decreased with increasing transceiver noise levels at three of five antennas. Water depth and transceiver noise were highly correlated at four of the five antennas, but noise levels increased with water depth at AFTC and decreased with water depth at DAVIS. Therefore water depth alone was not completely predictive of detection efficiency. Water depth was significantly correlated with detection efficiency at only one antenna of the five. However, these discrepancies were likely due to low sample sizes for efficiency estimates (and the fact that DAVIS typically had 100% efficiency) and changing operator conditions. Furthermore, the AFTC SPI was situated so that both A1 and A3 contacted the bridge abutment. This resulted in coupling of the antennas to the rebar in the concrete structure of the bridge. The DAVIS SPI was not coupled to any such structure. This difference could have resulted in differences in antenna response to changes in water depth. Based on impressions during day to day operations detection efficiencies, noise, and water depth were closely related.

Multiple measures of PIT tag detection efficiency at the SPIs were relatively consistent (AFTC: 78%, 69%, and 71%; DAVIS: 96%, 87%, 84%). The neutrally buoyant float measure seemed to be the most reliable since the operator knew that the tag was definitely passing the antenna. This measure resulted in detection efficiencies of 78 ± 3% (mean ± SE) and 96 ± 4% at AFTC and DAVIS, respectively. Other methods relied on volitional fish movement and were more suspect. For example, efficiencies based on coho released above the DAVIS SPI after capture in the screw trap and PIT tagging assumed that all of those coho moved downstream after the release. This is not necessarily a good assumption. Based on previous work with steelhead, up to 3% of fish moved above a trap do not necessarily move downstream (Ward and Slaney 1988). Also, estimates of fish detected at SPIs and then captured in the screw trap (combined efficiency of 96%) depended on the assumption that PIT tagged fish captured in the screw trap moved only while SPIs were operational. Although detection efficiencies varied between sites, with operation, and method of determination, values were typically over 70% and those recorded at DAVIS exceeded those efficiencies previously reported for other pass-through systems (Zydlewski et al. 2001). Furthermore, when the two SPIs were used in combination their efficiency, 97 % with CI of 91-100%, greatly exceeded other methods of quantifying fish abundance.

Efficiency of PIT tag detection using the backpack detector was very consistent between operators. Overall detection rates were on the low end of what has been reported in the literature for efficiencies of electrofishing units (33-65%, Pratt 1952; Webster et al. 1955; Lennon and Parker 1957). However, this type of recapture produced valuable information on an individual fish without physically capturing the fish. This allowed the researcher to avoid the many possible negative impacts of electrofishing and particularly the higher probability of mortality and injury associated with repeated electrofishing (Gatz et al. 1986; Mesa and Schreck 1989). Backpack efficiencies were within previously identified levels for other portable PIT tag detection units, 25 – 84% (TI systems, Morhardt et al. 2000; Roussel et al. 2000; Zydlewski et al. 2001). The rate of scanning was based on the feasibility of scanning the entire creek within a two week period. However, this method allowed determination of fish movement within a short period of time assuming little movement between scans.

The high efficiency and predictability of detecting PIT tags with SPIs is likely to allow more accurate estimates of fish movement, migration patterns and population abundance than has been available previously. Other possible applications of these techniques include precise location of individuals to habitat characteristics and further determination of interactions between individuals.

Evaluation of fish movements, migration patterns, and population abundance with Streamwidth PIT tag Interrogation systems: II. Biological Validation

Abstract:

In Fall 2001 1,588 juvenile (< 100 mm FL) salmonids (7 coho salmon, 482 cutthroat trout, and 1,099 steelhead trout) were PIT tagged upstream of two Streamwidth PIT tag Interrogation (SPI) systems (in 9 sites approximately 1 linear km each). Age at tagging for both cutthroat and steelhead was principally 1 year. SPIs recorded over 390,000 detections from October 2001 to 31 July 2002. Fish from all tagging locations were detected moving past the SPIs. Steelhead and cutthroat were typically detected moving in the Spring (from April – June, coincident with smolting). Steelhead were also detected moving past SPIs at lower numbers in the Fall and Winter (20% of the total number detected). Travel time between SPIs (downstream movement) was highly dependent on time of year. Travel time in the Spring was significantly faster (34.4 ± 7.0 h, mean ± SE) for all species than travel time during any other time of year (763.1 ± 267.0 h). Fish migrating in the Spring were the same age as those that were never detected. Migration patterns recorded with SPIs were similar to those recorded at the screw trap. Peak of steelhead migration recorded at the two SPIs was 11 May and 12 May and the peak at the screw trap was recorded on 17 May. Steelhead smolt production estimates using SPIs (3,802 with 95% confidence interval of 3440 - 4245) was similar to those using more standard screw trap methods (approximately 5,400). All species used the faster-moving/deeper section of the creek at both SPIs. A backpack PIT tag detector was developed and used as another remote "recapture" for additional accuracy in estimating population survival and recapture probability. Fifty-four individual fish were re-located. All PIT tag data were used to calculate survival and recapture probabilities using the Cormack-Jolly-Seber population model. Survival for naturally produced steelhead was highly related to fish size. Recapture probability depended greatly on season where probability of recapture was highest in Spring (29.5%) and relatively low in all other seasons (< 7% in Fall, Winter, and Summer). These techniques make available to researchers and fish managers an accurate assessment of life history characteristics and population dynamics of salmonids in small streams/tributaries at one-third the labor of screw traps and avoids handling the fish when they are sensitive to stress.

Introduction:

Commonly researchers identify life history characteristics of salmonids in small streams using field intensive methodologies that require multiple physical recapture of individuals (Juanes et al. 2000; Bell et al. 2000; Hilderbrand and Kershner 2000). Characteristics reported include smolt number, parr abundance, age structure, fish size, population size, survival, habitat use, seasonal and annual movements. Common methods include smolt traps, weirs, multiple electrofishing, and marking. Population dynamics (size, survival, and recapture probability) introduce another level of complexity, application of mathematical models. Using current methods, excessive field work is required to accurately estimate population size. This paper applies remote monitoring techniques that boost sample sizes, particularly number of recapture events, and increases efficiencies associated with those events, increasing the accuracy of the estimates.

Smolt abundance estimates traditionally include mark-recapture techniques (Hubert 1996). These techniques require one tagging event and at least one recapture event at minimum to estimate efficiencies of the techniques themselves. More traditional studies estimating salmonid population abundance incorporate capturing juveniles leaving as smolts in the Spring and estimating the total population from the number leaving. These types of estimates rely on the assumption that migration occurs only in the Spring (e.g. Seelbach 1993). With the newly developed PIT tag systems a known number of fish can be marked above a fixed reference point and continuously monitored past a point (all year). This allows a less laborious technique for quantifying population size and enables researchers to track population abundance, migrational timing of known origin fish as well as adult return timing by using remote and continuous monitoring of individuals past a fixed site.

Several studies have presented the use of portable PIT tag detectors for gathering recapture and habitat use information without having to physically capture the fish (Morhardt et al. 2000; Roussel et al. 2000; Zydlewski et al. 2001). This method affords the advantage of not physically harming the fish from repeated electrofishing (Gatz et al. 1986; Mesa and Schreck 1989). In this study a portable unit was designed to boost recaptures and gain information on individuals that did not migrate in the Spring (when they were expected to migrate). Coordination of individual recapture with abundance data collected with stationary pass-through systems creates the type of robust data set that vastly improves standard collection of valuable life history information. Ultimately, this allows the critical measure of population assessment, survival through the entire life cycle at multiple time points for individuals.

Monitoring biological characteristics of species throughout their life cycles is critical for understanding long-term changes in populations. Such long-term changes can be affected by events such as concerted supplementation of natural populations or restoration and recovery actions such as habitat restoration. A large gap in our knowledge of Pacific salmonid life history includes survival estimates for multiple life stages. Specifically, there is a critical lack of data from tributaries on juvenile survival, habitat use, and migration timing.

Abernathy Creek has naturally spawning populations of coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss*) and cutthroat (*O. clarki*) trout. Juvenile and adult coho salmon have been observed in Abernathy Creek each fall. The Washington Department of Fish and Wildlife (WDFW) conducts spawner surveys for steelhead each year. However, detailed information about juvenile life history characteristics, especially for coho, is largely unknown. We used passive monitoring methods to establish the following for steelhead and cutthroat trout: juvenile size and age in the fall, migration timing, age at migration, travel time, daily movement patterns, smolt abundance and stream use. Winter survival and probability of recapture were also estimated for steelhead.

The objective of this study was to acquire baseline information on the life history characteristics of three salmonids using newly developed PIT tag stream width PIT Interrogation Systems. This involved verifying that the baseline data, juvenile migration timing and smolt production, would be at least comparable to more standard methods of collecting similar information.

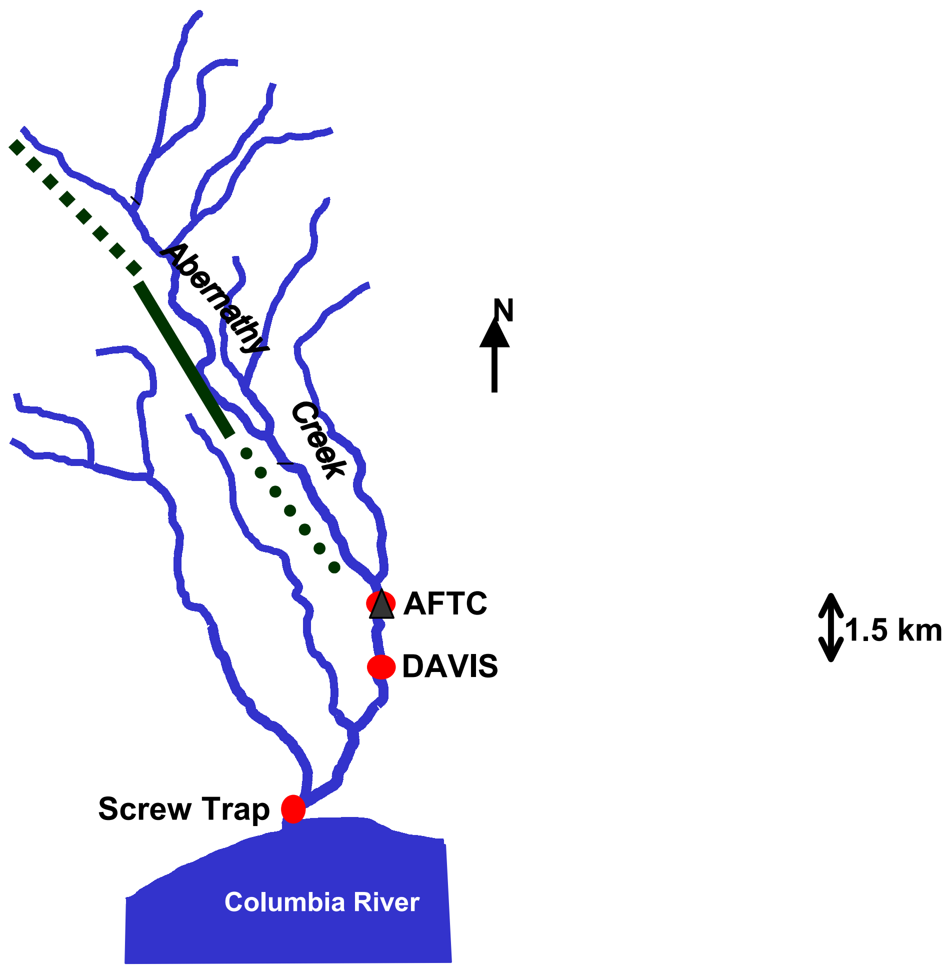
Methods:

Fish Capture and Tagging

In August 2001 two Stream-width PIT Interrogation systems (SPIs) were installed on Abernathy Creek (Figure 1). The systems incorporated full-duplex PIT tag technology. These systems were optimized for detection of 23 mm PIT tags (23 mm long, 3.4 mm wide, 0.6 g in air). The two SPIs were downstream of all electrofishing sites and were designed to detect all PIT tagged fish passing them. Water depth and temperature were recorded at the AFTC SPI using a Vemco temperature and depth logger.

Nine distinct sites (7.9 linear km) of Abernathy Creek (17.5 km total linear length) were electrofished (Figure 1). The sites ranged in linear length from 500 – 1250 m (Table 1). Three of the nine sites were electrofished for abundance estimates (see below) and the remainder were electrofished to maximize capture of fish greater than 100 mm. As fish were collected they were maintained in buckets until processed. Fish were anesthetized with 25 ppm clove oil, fork length (FL) and weight were measured, scales placed in envelopes, and a 23 mm PIT tag inserted. PIT tag insertion involved using a pointed scalpel blade to create an incision approximately 3 mm long (smaller than the diameter of the tag, 3.4 mm) and pushing the tag through the incision into the body cavity of the fish. When the PIT tag was inserted the area was wiped with a KimWipe and a small amount of antibiotic ointment was swabbed on the area. Fish were then allowed to recover in a flow-through container in the creek and were released into the stretch from which they were captured within one hour of tagging.

FIGURE 1. Schematic of Abernathy Creek located in Longview, WA. The location of the AFTC SPI is depicted with a circle and triangle. The location of the DAVIS SPI is depicted with a circle. The lower, middle, and upper electrofishing sites are depicted with a dotted, solid, and dashed line, respectively.



A total of 1,588 salmonids were tagged. Juvenile salmonids were tagged if their FL exceeded 100 mm. A total of 1,099 steelhead trout, 398 cutthroat trout, and 7 coho salmon were PIT tagged (Table 1). An additional 84 cutthroat were PIT tagged in two smaller tributaries of Abernathy Creek.

TABLE 1. Tagging site specifics and numbers of salmonids PIT tagged per site in Fall 2001 in Abernathy Creek.

Site name	Tagging Date	Site length m	Number of steelhead tagged	Number of cutthroat tagged	Number of coho tagged
L1	10/5/01	750	169	0	1
L2	10/4/01	500	119	9	0
L3	10/3/01	850	145	15	3
M1	9/27/01	1250	204	49	0
M2	10/1/01	750	138	29	0
M3	10/2/01	1000	156	32	1
U1	9/18/01	750	79	73	0
U2	9/19/01	800	66	66	1
U3	9/25/01	1250	23	125	1
TOTAL		7900	1099	398	7

On each sampling date every 5th steelhead (n = 99) was paint marked (pink) in the anal fin as well as PIT tagged and every 10th steelhead (n = 90) was paint marked (yellow) in the anal fin but not PIT tagged. Non-toxic acrylic paint was injected with a 26 gauge needle between two anal fin rays. This was used to determine capture rates of tagged and untagged fish captured at the screw trap in the Spring.

Fish Aging

Scales were collected into envelopes in the field. All scales were placed on scale cards and pressed with acetate. A subsample of scales was then read on a microfiche and age determined using standard aging procedures (DeVries and Frie 1996). The subsample was conducted randomly by selecting every fifth scale card and reading all of the scales on that card. Of the 1975 scales collected, a total of 645 (n = 366 for steelhead, n = 212 for cutthroat, and n = 67 for coho salmon) were read by at least two people. Age could not be determined for all of the samples because some scales were unreadable or regenerative. If readings by two people did not agree a third person read the scale and if there was agreement between two readers that value was used. If all three readings did not agree the reading was discarded.

TABLE 2. Status of subsampled scales from salmonids electrofished in Abernathy Creek in Fall 2001.

Scale status	Steelhead trout	Cutthroat Trout	Coho salmon
Successfully aged	150	74	40
Unreadable/regenerative	200	116	19
Discarded	16	22	8

Parr Abundance Estimates

Abundance surveys were conducted in a section of each of three sites (L2, M2, and U2) of the nine sampled. At these sites electrofishing removed all fish from the block-netted site. Block-netted sites were 50 linear m (0.47 km^2), 40 linear m (0.31 km^2), and 65 linear m (0.54 km^2). After each pass with the electrofisher all fish were quantified by species. In site L2 steelhead were also quantified based on whether they were larger than 100 mm (large enough to tag). If the total number of salmonids collected during subsequent passes was greater than 10% of the first pass number an additional pass was conducted. This was conducted for up to 5 passes through the site. Juvenile abundance was then estimated using the depletion model of Zippin (1958).

PIT tag Monitoring: SPIs

Tagging data were uploaded to the regional database, PIT Tag Information System (PTAGIS; PSMFC 1998) on a daily basis. Files included information on tag date, tag site, tagging method, temperature, migratory year, capture method, release site, river km, and release data. Files also included information on individual fish tagged on that date: PIT tag code, species, stock run timing, fish rearing environment, length, and weight. Related data entry occurred subsequent to all field events. Data entry was proofread and double checked for accuracy before uploading.

Every 12 h the SPIs uploaded continuous detection data including transceiver diagnostic information, detected PIT tag codes with associated antenna of detection, and time stamps to the PTAGIS database. Information on fish movements were acquired from querying the PTAGIS database. Database queries in this report include all unique detections by species from time of tagging until 31 July 2002.

Patterns of movement past the SPIs were continuously recorded and allowed discernment of peak movements in and out of the creek. These data also allowed determination of travel time between antennas (see Figure 1). Travel time was calculated for all fish pooled and then broken down by species (steelhead, cutthroat, and coho), season (Fall = October - December, Winter = January - March, Spring = April - June, Summer = July), and location (AFTC to DAVIS and DAVIS to screw trap). A two-way ANOVA was conducted to determine if there were differences among species and season for travel time between SPIs and from DAVIS to the screw trap. Continuous movements were broken down into movements conducted during each hour of the day. The number of fish recorded moving during each hour of the day in October 2001 (representative of Fall movements) and May 2002 (representative of Spring) were reported.

Continuous data records demonstrated which area of the creek at each SPI was used most, e.g. if fish moved most through A1 or B1 then they were moving in the deepest and fastest moving water at both sites. Categorical analysis (Chi square and z-test) of the frequency of detection on each antenna was conducted for all movements as well as for movements of each species at each site.

PIT tag Monitoring: Backpack

One complete creek survey was conducted (2 July 2002 to 24 July 2002) with the portable detection system after the Spring migration was complete. Efficiency tests were conducted as detailed in Section I. Backpack detections of individuals were recorded, flagged at the creek, and GPS measurement taken of the location. Notes were taken to determine if fish appeared to be stationary or if the fish moved away from the site of detection. All sites where fish were located were visited a second time to determine if the fish may have moved from the site.

Smolt Production Estimates

A rotary screw trap was operated 2.9 km downstream of DAVIS from 2 April – 21 June 2002. All captured fish were identified to species, counted, and scanned for PIT tags. Fish with PIT tags were anesthetized, PIT code recorded, length and weight measured, and a gill tissue biopsy was taken for analysis of gill Na^+,K^+ - ATPase activity levels (per McCormick 1993). Steelhead larger than 100 mm were examined for anal fin paint marks. On every Monday, Wednesday, and Friday coho salmon greater than 100 mm FL were anesthetized with MS222, measured for length and weight, scales taken for age, PIT tagged and released 20 m upstream of DAVIS. Efficiencies of the SPI and screw trap were estimated based on these releases. Similarly, the screw trap was evaluated for efficiencies based on recapture of fin-clipped coho salmon and steelhead released approximately 100 m upstream of the trap. Total smolt production was then estimated based on the efficiency of the trap and the total number of individuals captured.

Based on SPI detections, captures of PIT tagged fish in the screw trap, and remote recapture using the backpack, estimates of survival and steelhead production were determined. Steelhead smolt production was also estimated based on overall efficiencies of electrofishing and backpack unit detections.

Other Life History Characteristics

One additional (to the screw trap) point of recapture that allowed determination of growth differences occurred the Fall following this study. An ongoing study examining cutthroat population dynamics in Abernathy Creek (Zydlewski 2002) required electrofishing in the Fall 2002. Twenty-six steelhead and 32 cutthroat tagged in the Fall 2001 were recaptured in multiple sections of Abernathy Creek in the Fall 2002.

The four different types of recaptures recorded throughout the study (SPI, screwtrap, backpack, and 2002 electrofishing) allowed determination of differences in tagging size and age of fish exhibiting different behaviors. Size at tagging (length and weight) was compared for all possible recapture types including those fish that had not been detected or recaptured using a one way ANOVA.

Survival and Recapture Probabilities

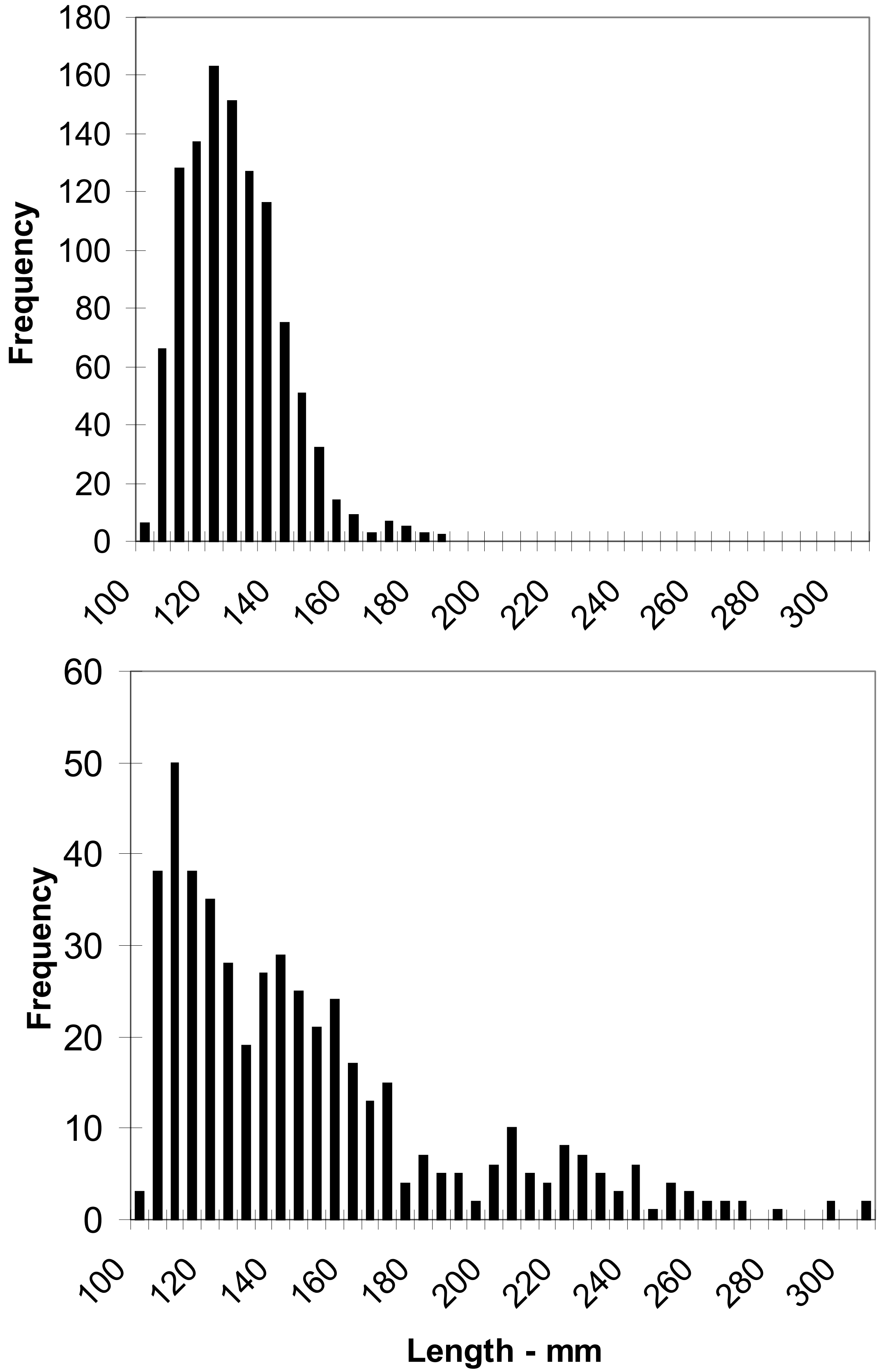
Survival estimates of steelhead trout were conducted using MARK (Colorado State University) where tag site was used as a grouping factor and length as a covariate of survival. Survival and recapture probabilities were estimated. Recapture probabilities were by season (Fall, Winter, Spring, and Summer as above).

Results:

Capture and Tagging

Length (Figure 2) and weight at tagging differed for steelhead and cutthroat. Steelhead larger than 100 mm FL ranged in size only up to 185 mm while cutthroat ranged in size up to 302 mm. Coho salmon encountered during fall tagging were typically smaller than 100 mm FL and were not PIT tagged. However, seven coho 100 – 109 mm FL were PIT tagged, one at L1, three at L3, one at M3, one at U2, and one at U3.

FIGURE 2. Length frequency distributions for steelhead (upper panel) and cutthroat (lower panel) trout PIT tagged in Abernathy Creek in the Fall 2001.



Fish Aging

A subsample (n = 645) of tagged fish were aged (Table 2). Steelhead age at tagging was principally 1 year (124 of 150 fish aged). Size at tagging for age 1 and 2 fish were not different (t-test, $p = 0.679$). Age was not significantly different (Mann Whitney U, $p = 0.495$) for those fish that were detected migrating in the Spring (n = 37 aged) than for those that were never detected (n = 113 aged).

Cutthroat age at tagging was primarily 1 year (46 of 74 fish aged). Length at tagging was positively correlated with age (CC = 0.387, $p = 0.0007$) where age 2 fish were significantly larger than age 1 fish (t-test, $p < 0.001$). Age was not significantly different (Mann Whitney U, $p = 0.198$) for those fish that were detected migrating in the Spring (n = 17 aged) than for those that were never detected (n = 56 aged).

Parr Abundance Estimates

Three of the nine major sampling sites of Abernathy Creek were electrofished for depletion estimates. Species quantified for each pass included steelhead, cutthroat, coho salmon, sculpins, and lamprey when present. Steelhead were the most prevalent salmonid encountered in all abundance sites. The estimated number of steelhead was greatest in the middle site of the creek whereas there were no cutthroat in the lower site and the highest number of cutthroat was in the upper most site (Table 3). Similarly, the number of coho was highest in the upper site but they were present throughout the electrofished sites of the creek.

TABLE 3. Population estimates (using Zippin 1958) of salmonids for each multi-pass site of Abernathy Creek.

Site	Total salmonids	Steelhead trout	Cutthroat trout	Coho salmon
L2	127 ± 7.1	92 ± 16	0	39 ± 2.3
M2	161 ± 3.0	102 ± 2.3	6 ± 0.8	50 ± 1.3
U2	119 ± 3.9	50 ± 1.2	13 ± 0.5	55 ± 3.3

In site L2 a total of 77 steelhead were captured during the abundance survey, 30 (39%) were large enough to tag. During the first pass through the site 17 out of 31 steelhead were large enough to tag. This number declined with each pass: 5 out of 13, 4 out of 17, 3 out of 11, and 1 out of 5.

The efficiency of the first pass for each abundance site was estimated as the number of steelhead captured in the first pass divided by the total number of steelhead captured throughout the unit. For each site, 31 out of 77, 28 out of 49, and 51 out of 100 steelhead were captured on the first pass. Average electrofishing efficiency was estimated as 49.3 ± 5.0 %.

PIT tag Monitoring: SPIs

Throughout the year over 390,000 detections were recorded at SPIs. A total of 361 unique individuals were identified. The majority of these were steelhead (n = 328). Thirty-one individual cutthroat and 2 coho salmon were observed also. Most movement out of Abernathy Creek occurred from 11 April to 29 May 2002, peaking on 11 May at AFTC and 12 May at DAVIS (Figures 3 and 4). The number of Spring migrants detected at the SPIs was 232 steelhead, 27 cutthroat, and 1 coho salmon.

Movements past the SPIs occurred throughout the year. Steelhead moved year round (Figure 3) whereas cutthroat primarily moved in the Spring (Figure 4). Very little data on coho salmon movement was collected, but movements were identified in both Fall and Spring.

FIGURE 3. Pattern of steelhead moving past (a) AFTC and (b) DAVIS SPI throughout the study period. Water depth is reported from a continuously recording VEMCO depth logger at AFTC.

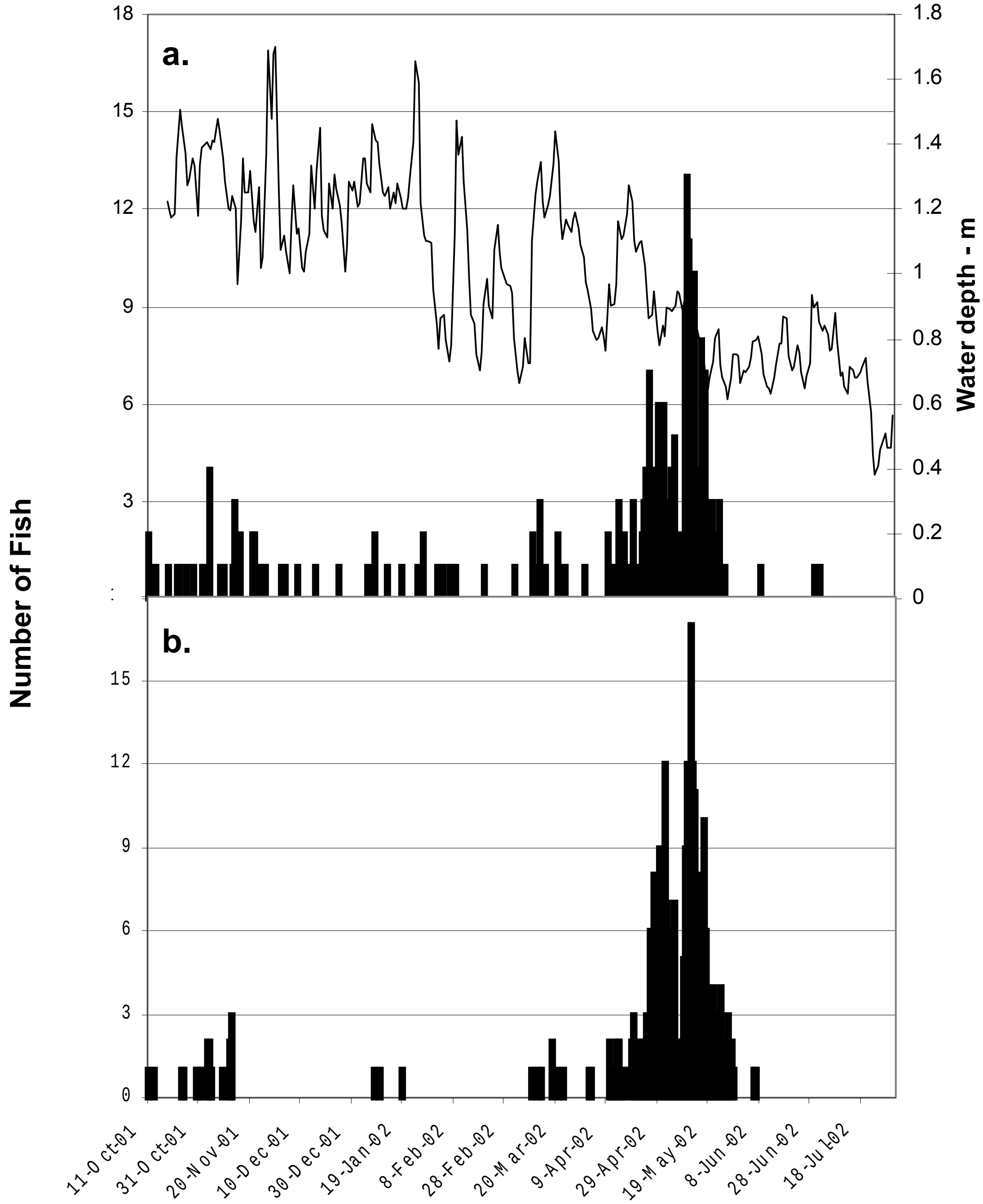
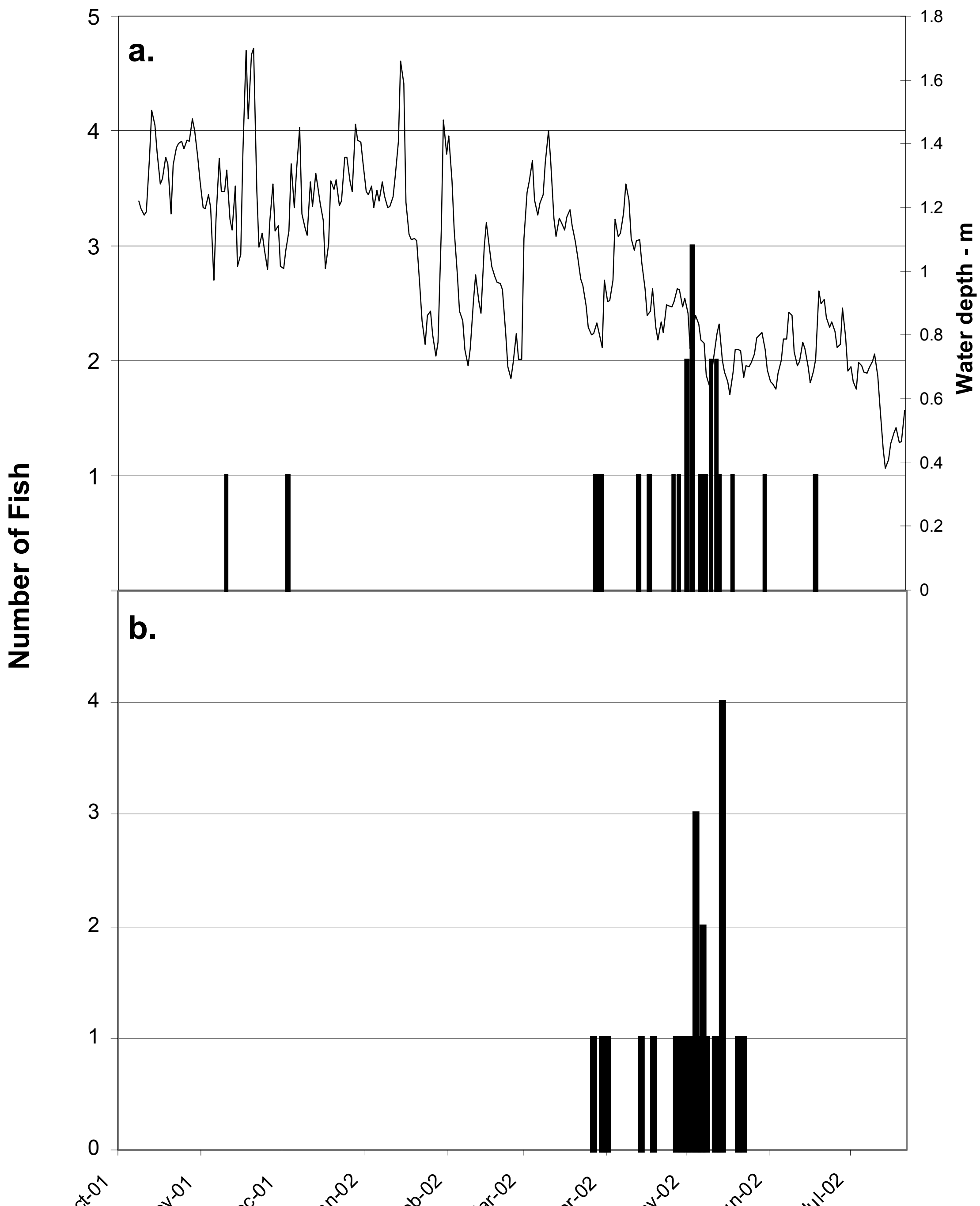
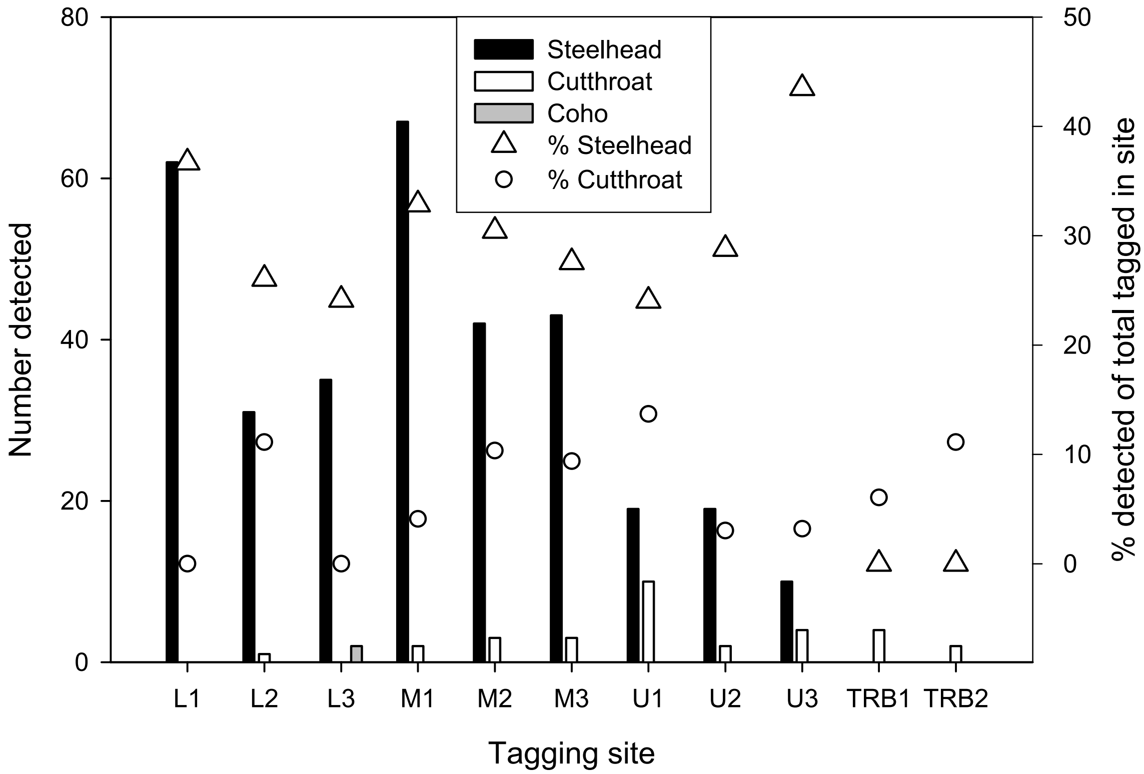


FIGURE 4. Pattern of cutthroat trout moving past (a) AFTC SPI and (b) DAVIS SPI throughout the study period. Water depth is reported from a continuously recording VEMCO depth logger at AFTC.



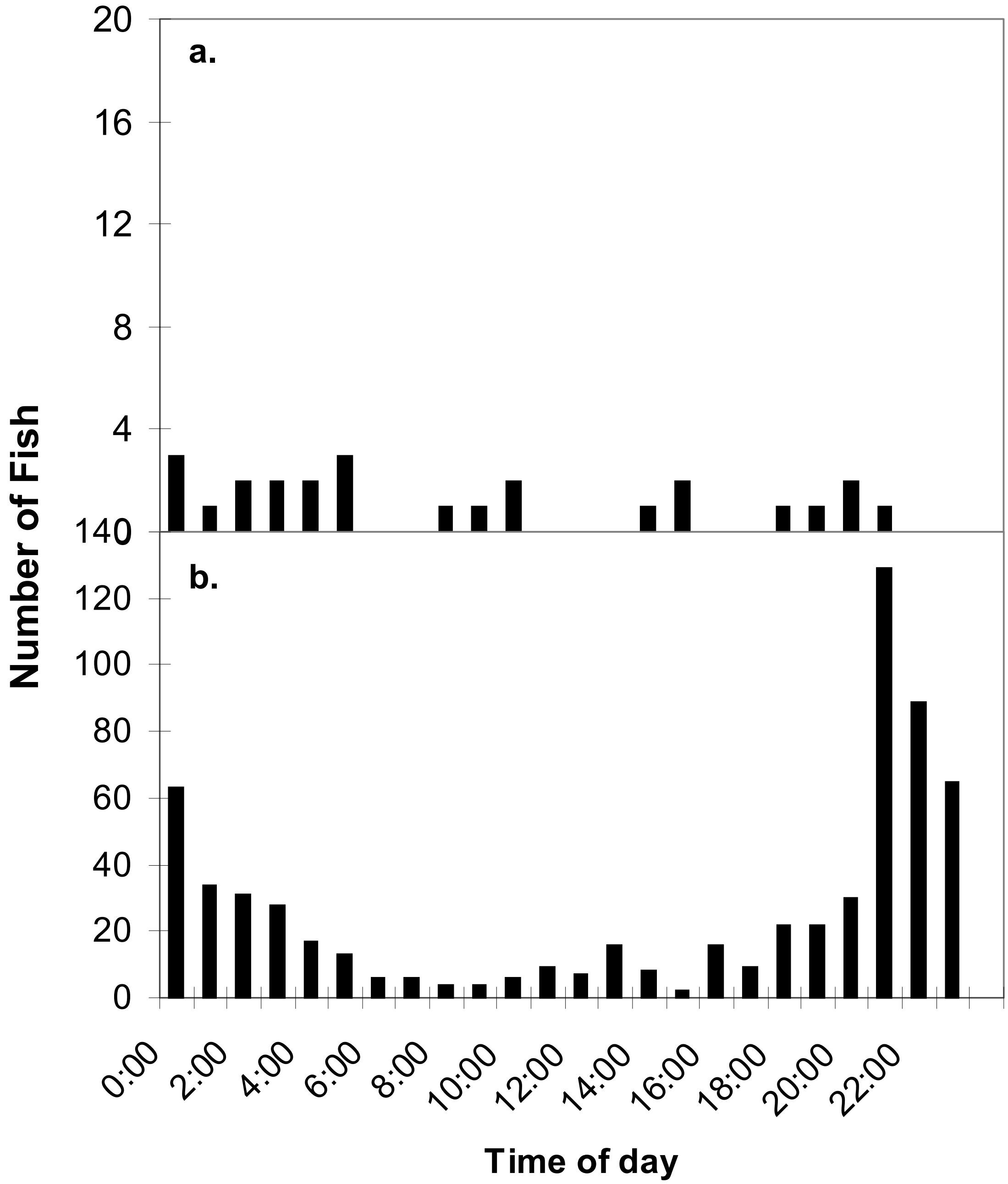
Fish detections consisted of individuals from all tagging sites (Figure 5). A larger proportion of steelhead per site (24.9 ± 4.1 %) was detected than cutthroat (6.5 ± 1.4 %). The maximum percent of fish detected in relation to number tagged in a site was 43.4 % of steelhead tagged in U3 were detected at the SPIs.

FIGURE 5. Number of individuals detected from each tagging location on Abernathy Creek (bars) and the percent of tagged fish detected in each site (circles and triangles).



Continuous records at both sites revealed that diel movement patterns did not differ substantially in Fall (although the number of fish was substantially lower) and Spring. Spring movements were spread out more evenly through the evening and Fall movements were more concentrated (Figure 6). Fish primarily moved between the hours of 0000 and 0600 in the Fall and from 2100 and 0600 in the Spring.

FIGURE 6. Number of individual fish (steelhead and cutthroat trout) recorded during each hour of the day throughout (a) October 2001 (Fall) and (b) May 2002 (Spring).



A number of individuals (n = 203) were detected at both AFTC and DAVIS. This allowed calculation of travel time between antennas. For all species pooled travel times ranged from 0.5 – 4,246.7 hours (Figure 7). Travel time for steelhead and cutthroat were not different, but for both species travel time differed according to season ($p < 0.001$). Most movements between SPIs for steelhead occurred in the Spring (n = 163) and these movements were quicker than in other seasons (Table 4). Similar patterns are seen for cutthroat and coho salmon. Length at tagging of cutthroat migrating between SPIs was significantly larger (135.3 ± 4.1 mm) than that for steelhead (127.0 ± 2.8 mm, $p = 0.018$).

FIGURE 7. Travel time from AFTC to DAVIS for all species during all times of year.

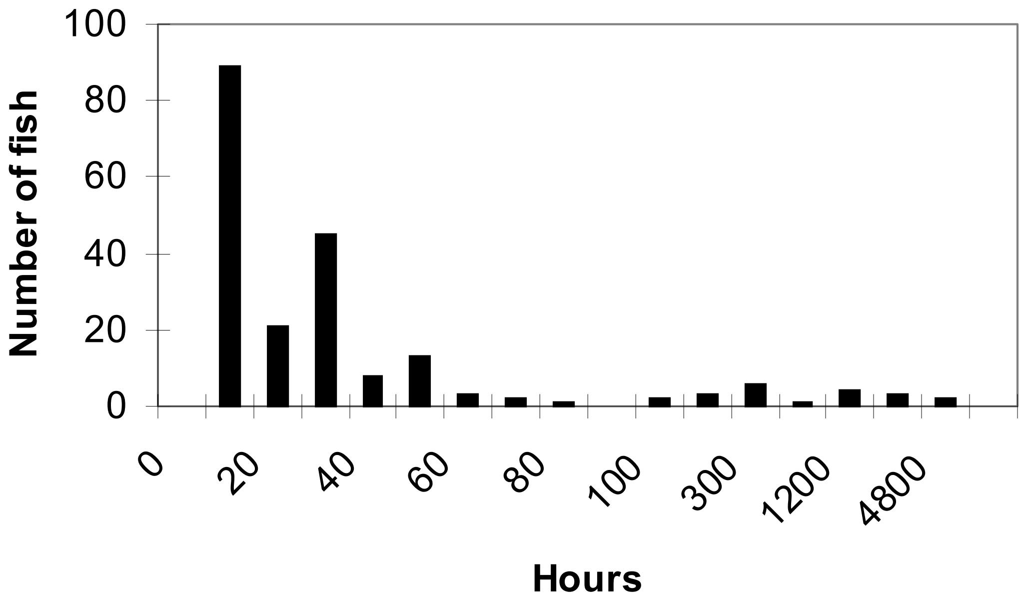


TABLE 4. Travel times for all steelhead, cutthroat, and coho that were detected at both AFTC and DAVIS. Travel distance is approximately 1.0 km.

Species	Fall	Winter	Spring	Summer
All fish	752.8 ± 483.7	763.1 ± 267.0	34.4 ± 7.0	437.6 ± 406.7
Steelhead	824.5 ± 528.8	763.1 ± 267.0	30.7 ± 5.9	30.9
Cutthroat	-	-	23.9 ± 7.3	844.3
Coho	35.8	-	0.87	-

Most fish detected at AFTC were detected on antennas A1 and A2. For all species pooled, 130 moved through A1, 141 moved through A2, and 25 moved through A3. There was no statistical significance to which antenna was used at AFTC (Chi-square, $p = 0.677$). A1 and A2 are relatively evenly spaced in the fastest moving water, A1 is on the deeper side of the creek and A2 is in the middle of the creek. One quarter of A2 is in slower water than the rest.

Most fish detected at DAVIS were at B1, in the faster moving area of the creek. For all species pooled (including those placed above DAVIS after removal from the screw trap), 567 moved through B1 and 182 through B2 (z-test, $p < 0.001$). This difference is significant for all fish and all species (with and without screw trap data).

PIT tag Monitoring: Backpack

The backpack unit was used in the Summer to detect a total of 54 individuals located throughout the creek. Twenty-five steelhead were identified between L1 and U3. Of those detected 14 moved out of the site upon relocation, one loose tag was found, and 10 tags were relocated in the same place upon relocation. Twenty-six individual cutthroat were located from L1-U3. Again, 14 moved out of the site upon relocation, two loose tags were found, 9 tags were relocated, and one was not resurveyed. Three individual coho were surveyed and remained in the same location upon relocation. All of these data were used as recapture information for population analyses.

Smolt Production Estimates

Downstream trapping occurred in Abernathy Creek from 2 April to 21 June 2002 except from 13 April 0845 hours through 14 April 1900 hours (34.25 h) and 9 May 0820 hours through 9 May 0845 hours (0.42 h). The total number of downstream migrants captured was 1,364 coho salmon, 807 steelhead smolts, 247 cutthroat smolts, 3,898 young of the year coho salmon, 3,543 young of the year Chinook salmon, and 15 young of the year chum salmon. Population estimates for all steelhead and cutthroat and coho salmon were calculated by extrapolating the number captured by the trap efficiency (Table 5).

TABLE 5. Population estimates (using efficiency extrapolation) of salmonids emigrating from Abernathy Creek. Trap efficiency is based on the proportion of a known number of marked fish released upstream of the trap that is recaptured in the trap.

Species	Estimate	Trap efficiency
Steelhead	5,400	15%
Cutthroat	1,650	15%
Coho	6,200	22%

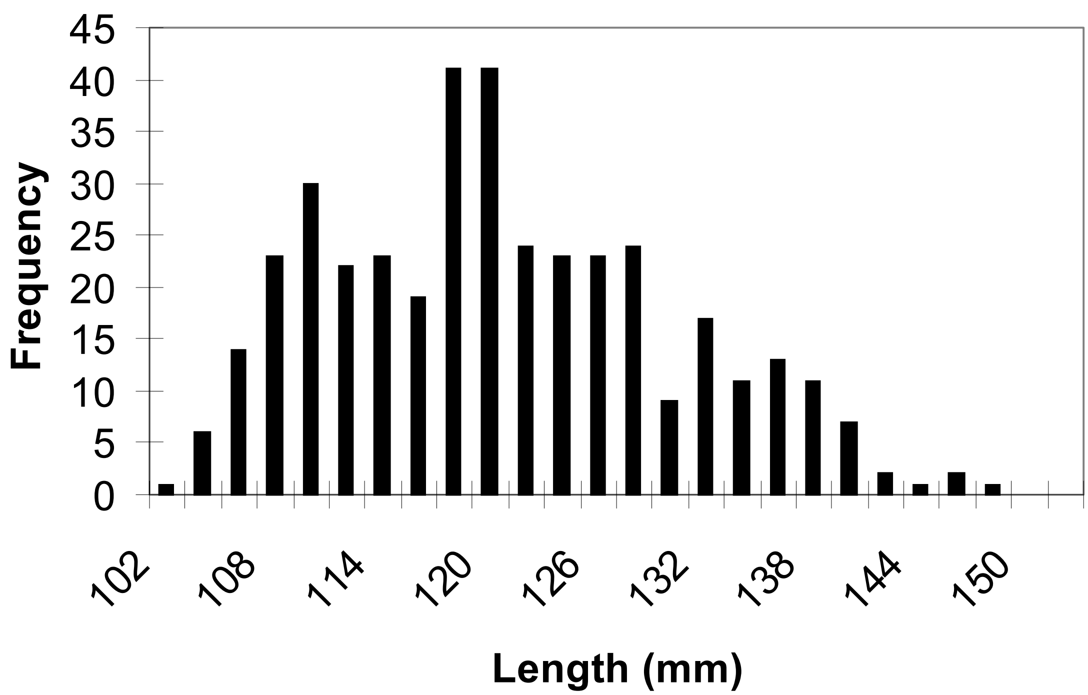
Smolt production for steelhead using PIT tag recapture information was approximately 3,802 (95% CI: 3,440 – 4,245). With 97 % (95% confidence intervals (CI): 91 – 100%) efficiency at the SPIs and 328 fish detected, the range (CI) of detection at the SPIs in the Spring was 328 – 360 (mean: 338). Based on the population estimates gathered during depletion estimates there were 1.72 (95% CI: 1.46 – 1.98) steelhead per linear meter of creek. Based on these estimates there were 25,550 – 34,650 fish in the entire creek (17.5 km). We only PIT tagged fish within 45% of the creek and of that only 39% were of PIT taggable size, leaving 4,484 – 6,081 fish available to tag. We tagged 1,099, 18.1 – 24.5% of those available. Extrapolating 328 - 360 (number of fish detected at the SPIs) by 18.1 – 24.5 %, adding 5% for tag loss (see Section III), and adding 55% to make up for the entire length of the creek, 3,802 (3,440 – 4,245) steelhead smolts emigrated in the Spring.

Smolt production can also be estimated based on tagging and backpack redetection alone. The proportion of creek electrofished and number of fish tagged accounted for a smolt production for steelhead of 4,640 (95% CI: 3,391 – 7,154). This value is based on the following: first pass electrofishing efficiencies were 49 ± 5% efficient, therefore a total of 2,243 (95% CI: 1,650–3,434) steelhead greater than 100 mm FL should have been available for tagging, and only 45% of Abernathy Creek was electrofished; this results in 4,984 (95% CI: 3,667–7,632) steelhead available for emigration in Spring. A proportion of fish did not leave in the Spring and approximately 5% could have lost tags (see Section III). Using the backpack PIT tag detector (24 ± 1.4 % efficient) 25 steelhead were accounted for as remaining in Abernathy Creek. Expanding based on efficiency and proportion of the river sampled (45%), 244 (95% CI: 202-325) steelhead were accounted for in July. Also, 26 (5 were also identified with the backpack so this number is reduced to 21 for calculations) steelhead were identified as remaining in the creek in the Fall 2002 (49 ± 5 % efficient). Expanding based on efficiency and proportion of river sampled, approximately 100 (95% CI: 74-154) steelhead remained. Therefore, a total of 344 (95% CI: 275-478) steelhead appear to remain in the creek after the Spring migration. Therefore, the total smolt production was 4,640, which is 4,984 less the remaining 344.

Other Life History Characteristics

A proportion (n = 387) of the screw trap captured coho salmon were PIT tagged and released above the DAVIS SPI. The coho ranged in size from 100 – 150 mm FL (Figure 8). The efficiency of the screw trap recapturing the PIT tagged fish was 32.2% (125 coho were recaptured in the screw trap). Of those released above DAVIS 324 (84%) were detected at the DAVIS SPI.

FIGURE 8. Coho salmon length frequency distribution for those tagged fish caught at a screw trap in Abernathy Creek.



A number of salmonids (37 steelhead and 11 cutthroat) tagged in Fall 2001 were recaptured in the screw trap in Spring 2002. One each of a yellow and pink paint-marked steelhead were captured in the screwtrap. Length and weight of recaptured fish did not differ between species. Steelhead averaged 174.9 ± 2.76 mm and cutthroat averaged 183.2 ± 5.5 mm. Fall tagging length of the recaptured steelhead was significantly smaller (131.6 ± 3.1 mm) than that of tagging length of recaptured cutthroat (141.9 ± 3.9, t-test, $p = 0.011$). Growth rate from time of tagging to recapture was relatively variable but not significantly different (Mann-Whitney Rank Sum Test, $p = 0.086$) between species (0.060 ± 0.0034 mm/d for steelhead and 0.051 ± 0.0035 mm/d for cutthroat). Similarly, growth rate in weight was not different between species ($p = 0.185$).

Steelhead migrations past the screw trap in the Spring of 2002 peaked on 17 May (Figure 9). Steelhead captures began on 4 April and subsided to 0 on 18 June. Cutthroat migrations past the screw trap peaked on 5 June (Figure 10) and the magnitude of the migration was smaller than that for steelhead. Cutthroat captures began on 3 April and never reached 0 before the trap was removed from the creek.

FIGURE 9. Numbers of steelhead trout captured at the screw trap located 2.9 km downstream of DAVIS on Abernathy Creek. Dates shown are for comparison with dates of detection using SPIS, the screw trap was only operated from 2 April – 21 June 2002 (indicated by horizontal solid bar).

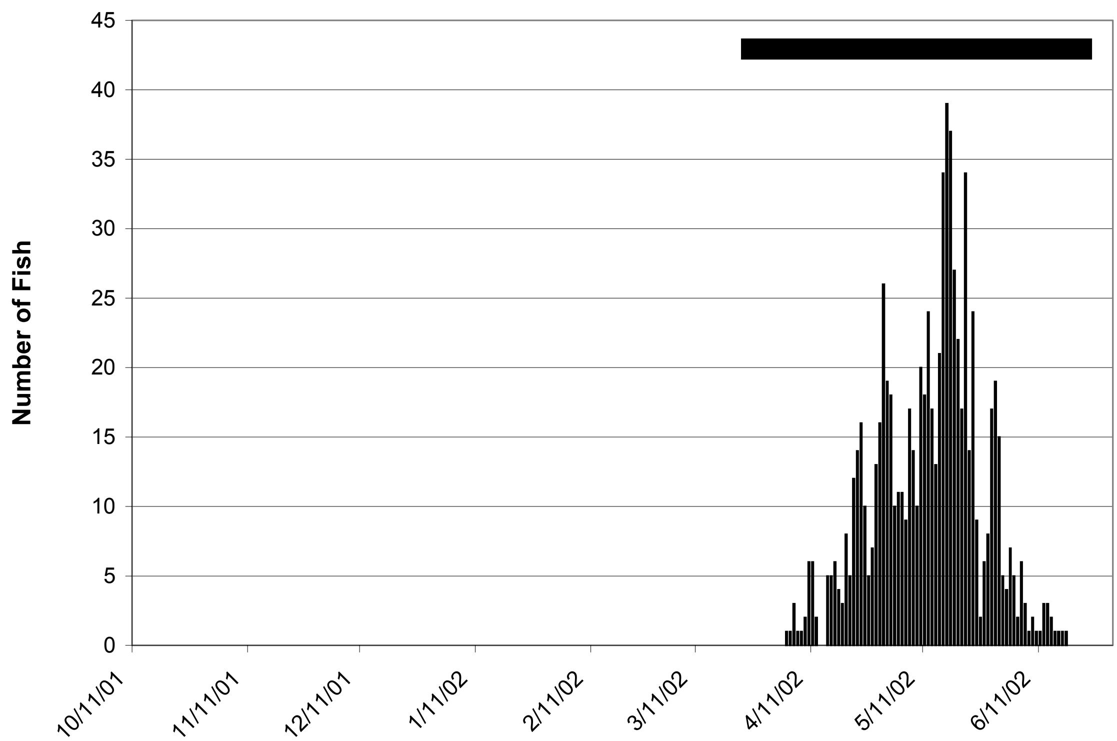
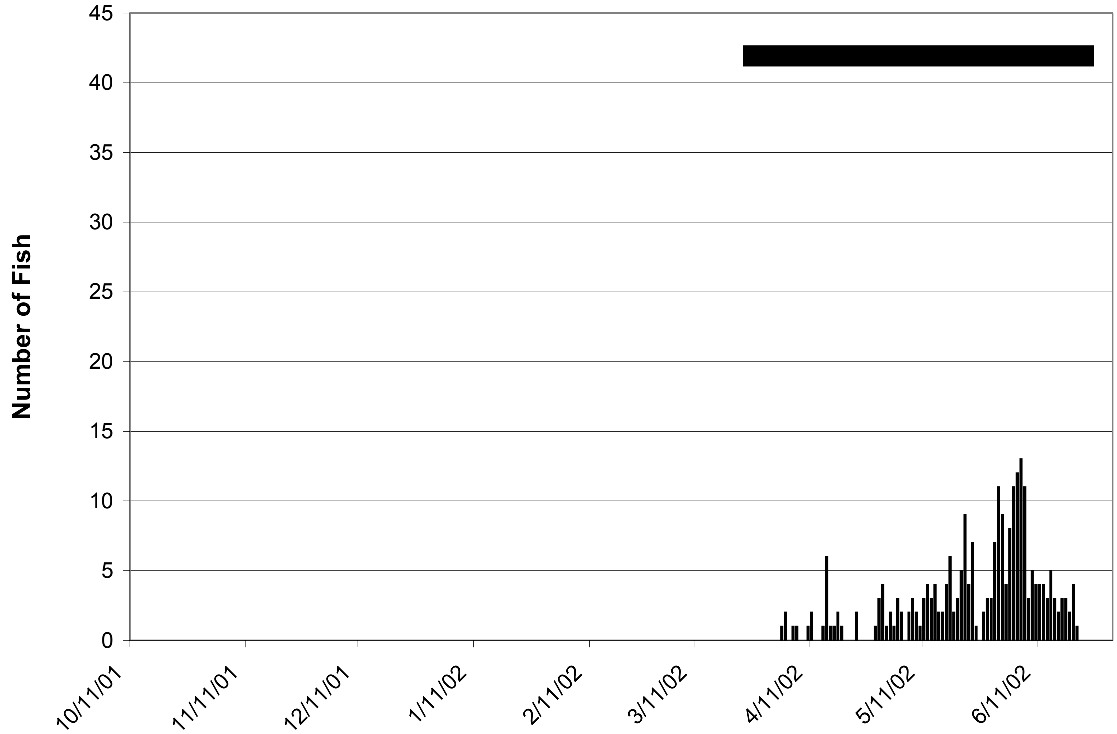
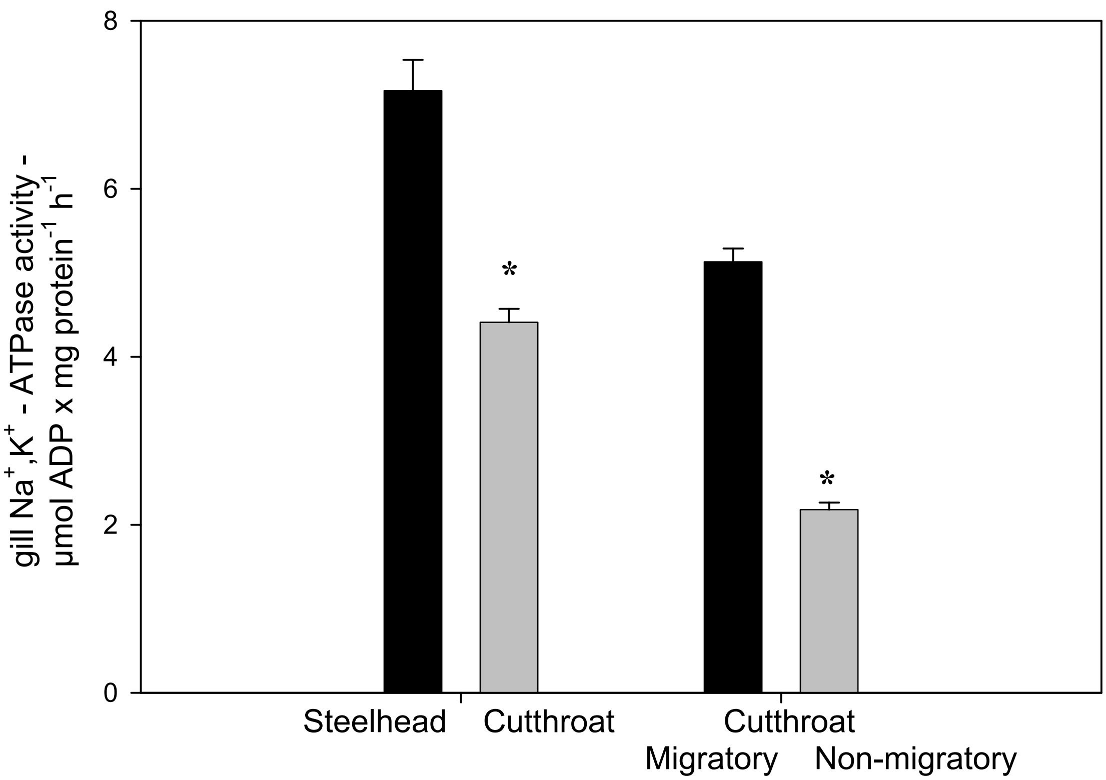


FIGURE 10. Numbers of cutthroat trout captured at the screw trap located 2.9 km downstream of DAVIS on Abernathy Creek. Dates shown are for comparison with dates of detection using SPIS, the screw trap was only operated from 2 April – 21 June 2002 (indicated by horizontal solid bar).



Steelhead and cutthroat were presumed to be smolts, actively migrating from tributary to the ocean. All previously PIT tagged steelhead captured in the screw trap were sampled for gill Na^{+},K^{+}-ATPase activity as a measure of smolting. Steelhead exhibited high activity levels averaging 7.18 ± 0.36 µmol ADP x mg protein $^{-1}$ h^{-1} (n = 31). These values were significantly higher than levels exhibited by cutthroat, 4.44 ± 0.16 µmol ADP x mg protein $^{-1}$ h^{-1}, n = 132 (t-test, $p < 0.001$, Figure 11). All cutthroat PIT or radio tagged (for another study, Zydlewski 2002) were examined for gill Na^{+},K^{+}-ATPase activity. Cutthroat levels were variable. J. Zydlewski (pers. Comm.) also obtained gill Na^{+},K^{+}-ATPase activity levels for cutthroat collected via electrofishing in the Fall. The average activity level for those fish was 1.94 ± 0.12 µmol ADP x mg protein $^{-1}$ h^{-1} (n = 18) and the maximum value was 2.80. These fish were considered "non-migratory." For this reason cutthroat captured in the Spring were further characterized based on their gill Na^{+},K^{+}-ATPase activity levels. Any cutthroat exhibiting levels below 2.8 were considered "non-migratory" and above 2.8 were considered migratory. The t-tests were re-run and steelhead levels were still significantly higher than migratory cutthroat levels (t-test, $p < 0.001$, Figure 11).

FIGURE 11. Gill Na^+,K^+-ATPase activity (μmol ADP x mg protein $^{-1}$ h^{-1}) of steelhead and cutthroat captured in the screw trap in Spring 2002. Migratory and non-migratory are cutthroat broken into categories based on gill ATPase levels. Values are mean ± SE. * indicates statistically significant differences ($p < 0.05$) within the paired bars.

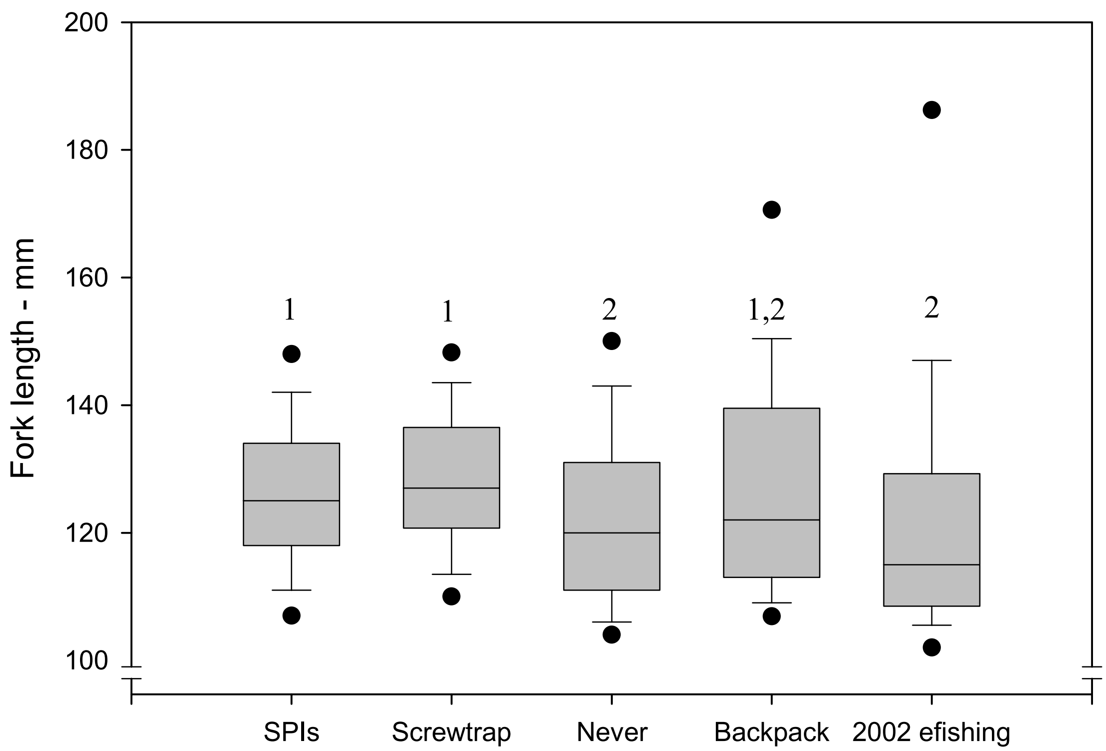


Travel time between detection at DAVIS and capture in the screw trap averaged 198 ± 150.7 h for steelhead that were tagged in the Fall, detected at DAVIS, and recaptured in the screw trap. One fish was detected at DAVIS in November and caught in the screw trap in May. When this outlier is removed the average travel time is 48 ± 10.6 h. Cutthroat travel time between detection at DAVIS and capture in the screw trap averaged 57.5 ± 17.6 h. Coho salmon travel time between detection at DAVIS and capture in the screw trap averaged 65 ± 11.4 h. Travel times did not differ between species (ANOVA on ranks, $p = 0.541$).

PIT tagged steelhead recaptured in Fall 2002 were significantly smaller (149.0 ± 5.2 mm) than PIT tagged cutthroat (180.8 ± 7.3) recaptured at the same time ($p = 0.021$, Mann-Whitney U). Weight at recapture was not different ($p = 0.055$, Mann-Whitney U). Length at tagging (Fall 2001) for cutthroat recaptured in Fall 2002 was larger (142.5 ± 5.9 mm) than that of steelhead (124.2 ± 3.5 mm, $p = 0.031$, Mann-Whitney U). However, growth rates in length and weight did not differ significantly between species ($p = 0.129$ and 0.344, respectively, Mann-Whitney U).

For steelhead recaptured at SPIs and in the screw trap (Spring migrants) length and weight at tagging (in Fall 2001) was significantly greater than fish that were tagged and never recaptured ($n = 671$, $p < 0.0001$). While those steelhead recaptured in Fall 2002 via electrofishing were significantly smaller than those recaptured by SPIs or the screw trap (Figure 12).

FIGURE 12. Steelhead trout fork length at tagging (Fall 2001) for the different recapture types used in this study. Box plots represent the mean, 25th and 75th percentiles, and dots represent the 5th and 95th percentiles. Differing numbers above boxes indicate statistically significant differences ($p < 0.05$).



Survival and Recapture Probabilities

Survival estimates, using the Cormack-Jolly-Seber Model, for steelhead using PIT tag recapture information were relatively high, 97 ± 1.7 %. The best recapture model incorporated FL at tagging as a covariate and had encounter occasions reported for each season of the year. The model results indicate that survival was a positive function of length and recapture probability was dependent on season. The probability of recapture during the four seasons analyzed was highest for Spring (29.5%) and lower for all other seasons (7% in Fall, 3% in Winter, and 3% in Summer).

Discussion:

Application of new techniques for remote monitoring of PIT tags (SPIs and backpack unit) has allowed quantification of many of the commonly reported salmonid life history characteristics and quantification of some unique characteristics. These techniques require only one fish handling event, continuous remote monitoring of movement past a site, and one complete creek survey. From this type of sampling we are able to report the following standard measurements of salmonid life history characteristics: Fall size distribution, Fall age distribution, age at migration, basic parr abundance estimates, survival estimates, recapture probabilities, and smolt production estimates. More interesting are the reportable measures not commonly reported in abundance and screw trap surveys: Fall size of Spring migratory salmonids, year-round migratory patterns, daily migration patterns, proportion of fish leaving identified sections of the tributary, travel time through the tributary, and habitat choice in restricted sections of the tributary. Furthermore, this study identifies a simple method for estimating smolt production that also allows quantification of the numbers of individuals remaining after the Spring migration.

In this study, additional information gained from also operating a screw trap includes verification of Spring migration patterns and smolt production estimates, calculation of an additional travel time within the tributary, and information on growth and physiological status of Spring migrants. Results indicate remarkable similarities in all comparable measures. Furthermore, the effect of PIT tagging in the Fall before Spring emigration does not seem to effect Spring movements of the fish based on equal probability of capture of PIT tagged and non-PIT tagged fish (anal paint marked) as well as similar size at migration of PIT tagged and non-PIT tagged fish. Even PIT tagging during the Spring emigration period did not drastically effect fish movement based on coho recapture after capture in the trap, PIT tagging, moving them 2.9 km upstream and recapturing them in the screw trap. The estimated efficiency of recapturing PIT tagged coho was 32.2% which was higher than recapture rates using fin-clipped fish moved only 100 m upstream of the screw trap (22%).

The most common salmonid life history characteristic reported for management purposes is smolt production. SPI smolt production estimates were similar to that reported from the screw trap on Abernathy Creek as well as that reported in the literature. Washington Department of Fish and Wildlife estimated outmigration of steelhead from Abernathy Creek as 5,400 based on trap capture efficiency of 15%. During the same year we estimated 3,802 steelhead smolts with the SPIs based on 97% (95% CI: 91-97%) efficiency. Similarly, Ward and Slaney (1988) reported smolt abundance estimates of 5,543 from a comparable tributary in British Columbia. Many estimates of smolt abundance are highly variable from year to year, e.g. Newcomb and Coon (2001) 3,097 – 11,118 and Ward and Slaney (1988) 2,104 - 11,897). This phenomenon was also evident in Abernathy Creek where the 2001 screw trap estimate of steelhead production was 10,590. Although steelhead production from Abernathy Creek varies annually within a year the estimate of production using the screw trap and SPIs was very similar, with the

SPIs having better efficiency (97% versus 15%) and offering a higher degree of certainty to the estimates.

Smolt production estimated using multipass electrofishing and backpack surveying was similar to that produced with the screw trap and the SPIs. A typical quandary for fisheries biologists is the variability and degree of success of accurately estimating numbers of emigrating smolts due to migration timing and high water events. Although the degree of accuracy associated with these techniques (24% for backpack and 49% for electrofishing, which is within literature reported efficiencies, 33-65% Pratt 1952) are not as high as using the SPI technique (approximately 97% efficient) they still exceeds the use of screw traps (usually 12 – 25% depending on the location). Screw traps have been reported to have efficiencies as low as 3% (Thedinga et al. 1994). Depletion and backpack surveying are generally more labor intensive than using SPIs but do not require dependence on continuous operations of a permanent structure and purchase of associated electronics. Also, the backpack technique does not depend on physically recapturing the fish and the extensive monitoring required by screw traps. These techniques can probably be improved by employing rigorous electrofishing practices and having multiple people running backpack PIT tag detectors to sample a larger proportion of the fish present. Another life history character quantified with these techniques is degree of residualism or quantification of numbers of fish that do not migrate (in this study this was approximately 7% of the steelhead population).

An important characteristic measured for population management purposes was Spring migration timing. In this study the SPI technique was verified with the more standardly used screw trap technique. SPI peaks of Spring migration for steelhead and cutthroat were amazingly similar to those reported from the screw trap and differences in timing can mostly be explained by travel time between sites. Peak Spring movement of steelhead at AFTC was on 11 May, with 31 h travel time to DAVIS, the peak there was on 12 May. The peak at the screw trap was recorded on 17 May. The travel time from DAVIS to the screw trap for steelhead averaged 48 h, but screw trap efficiency was relatively low, and the fish may have avoided the trap (also reported in Newcomb and Coon 2001). Movements of cutthroat were slightly less predictable than steelhead. Peak movements at AFTC occurred on 12 May and the peak at DAVIS did not occur until 19 May and the screw trap peak did not occur until 5 June. These discrepancies could be related to Abernathy Creek having a mixed population of cutthroat. The variability in life history characteristics observed for cutthroat (e.g. size at tagging and migration, and gill Na^+,K^+-ATPase activity) in this study indicate that there are resident and searun populations represented in Abernathy Creek. Variability in life history type would explain the variability in movement and physiological data collected at the screw trap.

Annual migration patterns described in this study emphasized the importance of looking at salmonid movements throughout the year rather than only during the Spring migration. For example, 67 steelhead (20% of the total number) were detected during the Fall, Winter, and Summer. These types of movements have been typically ignored in population estimates (Seelback 1993). Similarly, many researchers/managers have ignored day time movements and estimate smolt abundance based on night movements alone (Newcomb and Coon 2001) but daytime and non-Spring movements seemed to be particularly important to steelhead in this study. On the other hand there was very little movement by cutthroat in non-Spring months. Therefore, year-round detection may not be as vital for some species, but determining the importance of this type of collection may require an extensive effort or the installation of SPI systems.

Recapture rates of fish at the SPI systems were comparable to those reported in the literature with electrofishing and multiple recapture events. Recapture rates for steelhead were approximately 30% and this was consistent for all tagged sections of the creek. Cutthroat recapture rates were significantly lower but this may also be due to the variability in life history types being expressed in Abernathy Creek. However, the values reported from our individual stream (approximately 11%) sites are similar to those reported for other stream resident populations of cutthroat. Hilderbrand and Kershner (2000) reported recapture rates of 16% using mark-recapture and two-way traps in Beaver Creek, Idaho-Utah. These resident fish were reported to move 0.33 – 3.3 km annually. These values were also similar for movements of cutthroat in Abernathy Creek. For example, juveniles moving from the upper most tagging site moved over 13.8 km.

Two unique features of the SPI systems were determination of daily migration patterns and travel time. Although these have been determined previously using snorkeling, radiotelemetry, electrofishing, and trapping techniques (e.g. Wood et al. 1993) the SPI techniques would greatly decrease the effort required. SPIs collect general biological information previously not easily quantified as side effects. These data are useful for determining appropriate times for more extensive monitoring of features such as habitat use at different times of day or time of day fish are associated with monitoring features (e.g. using a bridge of SPI structure for cover).

Although the Cormack-Jolly-Seber estimate of survival appeared relatively high and are moderately reliable, the estimates of recapture probability (30% in Spring) seemed appropriate based on detection rates at that time of year. As more data are collected this type of survival model will become more reliable and provide a more accurate estimate of survival and recapture probability. Because the data being collected are individually-based they will provide more specific information but the estimates may be lower, 10% or more, than more standard methods of estimating populations (Juanes et al. 2000).

With multiple detections we were able to determine the effects of size at tagging on subsequent life history characters. For example, length at tagging was an important covariate for estimating survival and recapture probability, where steelhead 124 mm were 97% likely to survive to be detected. Also, the steelhead detected at SPIs and in the screw trap were significantly larger than those that were never detected again. This is relevant for determining which year classes that are likely to contribute to adult returns. SPIs will become important for detecting returning adults as well. As this occurs, estimates of adult run size and smolt to adult survival will be possible. Furthermore, AFT Center is developing a steelhead broodstock and will begin releasing juveniles into

Abernathy Creek, and the data collected in this study can be used to predict the size the fish should be in the Fall before release.

While most studies of population dynamics would strive to interrogate an entire stream width others may only want to interrogate part of a system (e.g. due to physical constraints). For this reason, it was interesting to discover that all species in this study chose the deeper, faster moving sections of the creek even when they had the opportunity to use a slower section. Ninety-two percent of fish moving through AFTC chose to move through faster water when they had an additional one-third of the creek (movement through A3) available for movement.

The techniques provided here provide researchers and fish managers a relatively accurate assessment of life history characteristics and population dynamics of salmonids in small streams/tributaries. Most importantly, these methods offer a monitoring tool that does not require handling of salmonids during a physiologically difficult life stage, smolting. The initial handling event can be as labor intensive as desired but subsequent monitoring requires very little labor. In this study tagging 1,588 salmonids required approximately 12 d of five workers' time where standard smolt trapping to gain less information (only abundance and individual information during Spring) would require up to 105 d of 2 workers' time.

Evaluation of fish movements, migration patterns, and population abundance with Streamwidth PIT tag Interrogation systems: III. Tagging Effects

Abstract:

To justify the use of 23 mm PIT tags in field and laboratory applications it must be determined whether the tagging process negatively affects the fish. A group of naturally produced juvenile steelhead trout was collected in the Fall, PIT tagged in the field, and transferred to the laboratory for observation. Wild steelhead retained 23 mm PIT tags at a rate of 97.6%. A second study was designed to determine the effects of 3-sized PIT tags (12 mm, 20 mm, and 23 mm) on survival and growth of individual hatchery steelhead and coho salmon. Coho salmon were also examined for tagging effects on smolting in the Spring. Retention of 23 mm PIT tags was 100% for coho salmon and 89% for steelhead. For both coho and steelhead growth rates over the entire study were not affected by tag size. Smolting (as measured by gill Na^+,K^+ ATPase activity and performance in 24 h seawater challenge) was not affected by PIT tagging. PIT tagging with 23 mm tags in the Fall should not result in growth affects that would be detrimental for subsequent survival of salmonids.

Introduction:

Annually approximately one million juvenile salmonids are tagged with 12 mm long PIT (Passive Integrated Transponder) tags in the Columbia River Basin (PSMFC 2000). Few studies have examined the immediate and long-term effects of PIT tagging on growth and physiological function as related to tagging. More recently larger PIT tags allowing larger read range are being applied in tributaries to the Columbia River. Coincident with these applications this study was designed to examine the effects of tagging with 23 mm PIT tags on tag retention, survival, growth, and effects on smolting of two species of salmonids.

To date the effect of PIT tagging on fish growth of salmonids has only been described as "preliminary data" (e.g. Ombredane et al. 1998; Juanes et al. 2000; Roussel et al. 2000, Zydlewski et al. 2001). Tag retention rates and survival post-tagging are more commonly reported (Roussel et al. 2000; Gries and Letcher 2002; Buzby & Deegan 1999; Wisniewolksi & Nabialek 1993; Moore 1992). Comparisons of behaviors post-tagging of tagged and untagged fish have also been reported, e.g. migration timing was similar for juvenile Chinook (> 3 g) with different types of tags (Prentice and Flagg 1987). However, PIT tagging is a ubiquitous procedure used to monitor many individual parameters, including growth, in the natural environment (e.g. Juanes et al. 2000).

To gain a better understanding of how tagging procedures influence the biological processes being measured when using tagged fish there needs to be a greater understanding of the effects of tagging on the individuals being tagged. The objective of this study was to verify the effects of PIT tagging individual fish. Three studies were conducted to accomplish this objective. The first study examined the effects of field tagging procedures (using 23 mm tags only) on steelhead trout brought back into the laboratory. The second study examined the effects of PIT tagging coho salmon with three different sized PIT tags and the subsequent effect of the tagging event on smolting. The third study examined the effects of PIT tagging steelhead trout with three different sized PIT tags.

Experiment 1: Wild subsample of steelhead

Methods:

On eight of ten sampling dates during Fall 2001 approximately 10 steelhead (n = 89 total) were measured, weighed, and PIT tagged at the field site and returned to Abernathy Fish Technology Center (AFT Center). On two occasions 10 steelhead were captured in the field and returned to AFT Center without tagging (control). Fish were maintained in flow through (well water at 12^{o}C) 1.2 m diameter circular tanks. Tanks were examined daily for tag loss and fish mortality. Fish were fed Bio-Oregon dry pellets daily at 1% body weight. Fish were re-examined (anesthetized, measured, and weighed) on 2 November 2001, 25 March 2002, and 16 May 2002 to determine growth rates. Fish were sampled for gill Na^{+},K^{+}-ATPase activity on 16 May 2002, then released into the creek on 17 May 2002.

Tag retention was calculated for tagged fish as 100 times the number of fish retaining tags divided by the total number of fish tagged. Survival was calculated for control and tagged fish as 100 times the number of fish alive in a group at the end of the study divided by the total number in the group at the beginning of the study. Average growth rates were determined between all sampling periods by calculating specific growth (Busacker et al. 1990). Two-way factorial ANOVA was used to compare length and weight for tagging groups. The two factors considered were date and tag treatment (control or tagged). In all cases the data were not normally distributed and were log transformed before running statistical analyses. Growth rate comparisons are only descriptive because although there was individual growth information for tagged fish individual growth rates on control fish could not be calculated since they were not individually marked.

Results:

Tag retention was 97.6%. A total of 89 fish were tagged and only 2 lost their tags. All fish that died during experimentation retained their tags. Overall survival was 72.9% for tagged fish and 66.7 % for control fish. Most mortalities occurred within the first three months of fish being moved to the AFT Center. On 16 November one control fish and three tagged fish were sampled for disease as a possible cause for mortality, however, results were inconclusive.

Size (length and weight) at each sampling point did not differ between groups (Figures 1 and 2). Over time both length and weight increased (Time effect 2-way ANOVA, $p < 0.0001$ for length and weight). Tag effects were not significant for either length or weight (Tag effect 2-way ANOVA, $p = 0.9680$ and 0.4544, respectively). There was no interaction between time and tag for length or weight ($p > 0.0662$).

FIGURE 1. Steelhead trout fork length taken over time for control fish and fish tagged with 23 mm PIT tags. All fish were collected and handled in the field (Abernathy Creek) and returned to Abernathy Fish Technology Center for observation of growth and survival. Values are reported as mean and standard error. There were no significant differences in length within time periods.

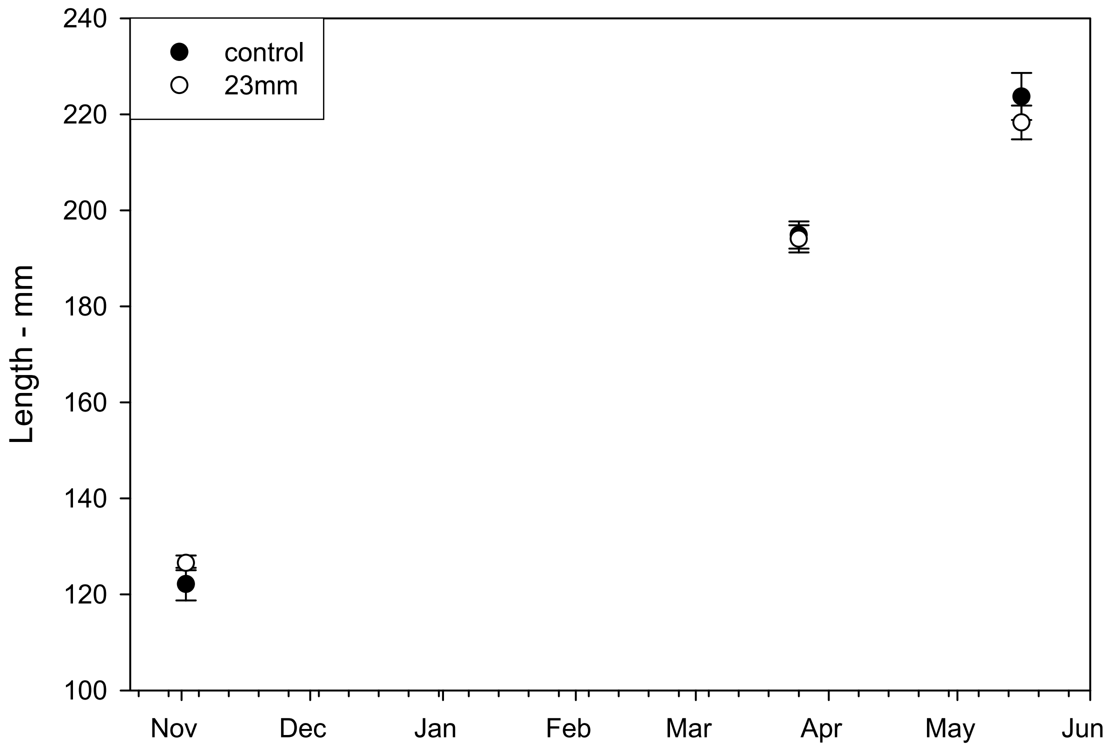
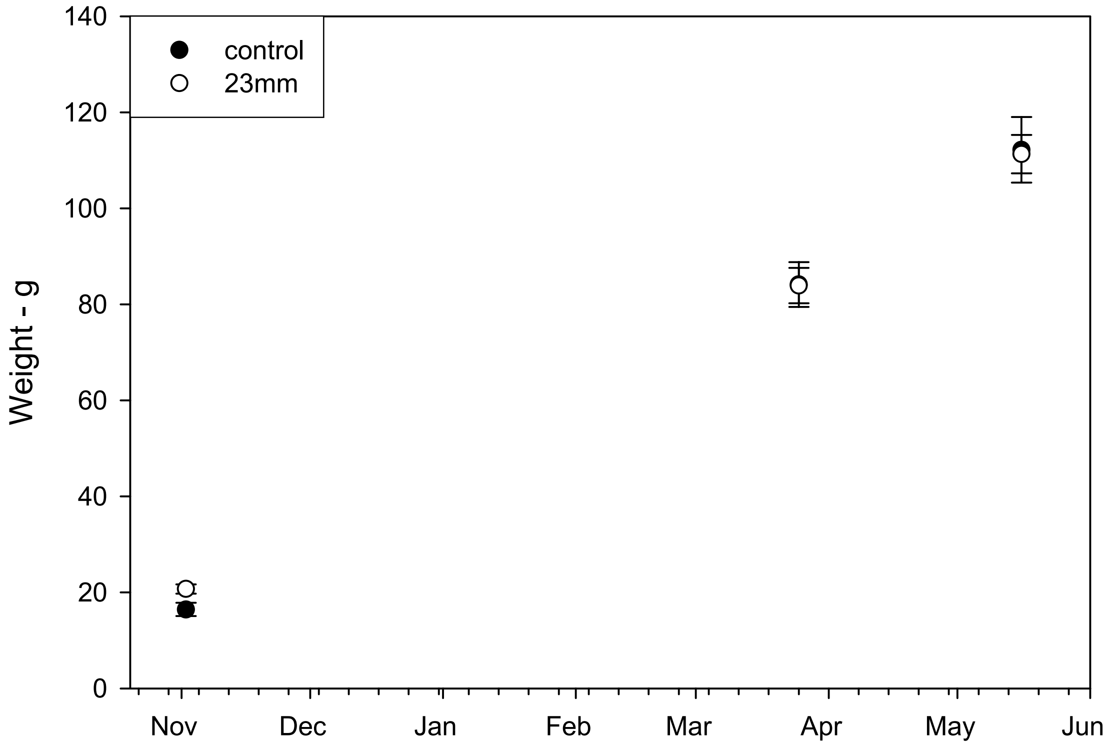


FIGURE 2. Steelhead trout weight taken over time for control fish and fish tagged with 23 mm PIT tags. All fish were collected and handled in the field (Abernathy Creek) and returned to Abernathy Fish Technology Center for observation of growth and survival. Values are reported as mean and standard error.



Growth rate (average difference of control fish) of control fish from November to April averaged 0.496 % g d^{-1} and 0.142 % mm d^{-1}. Growth rate of tagged fish during the same period averaged 0.425 % g d^{-1} and 0.130 % mm d^{-1}. Growth rates during the second time period were 0.240 % and 0.236 % g d^{-1} and 0.115 % and 0.098 % mm d^{-1} for control and tagged fish, respectively. Gill Na^{+},K^{+}-ATPase activity did not differ between groups (t-test, $p = 0.927$) and was relatively low for both groups. Control fish levels were 2.01 ± 0.255 µmol ADP x mg protein $^{-1}$ h^{-1} and tagged fish levels were 1.98 ± 0.144 µmol ADP x mg protein $^{-1}$ h^{-1}.

On 17 May 2002 steelhead from this study were released into Abernathy Creek approximately 500 m above the AFTC SPI. Sixty-two of these fish were released with PIT tags and 14 were released untagged.

Experiments 2 & 3: Coho and steelhead tagged in the laboratory

Methods:

Two laboratory experiments were conducted to examine the effects of tagging and tag size on juvenile salmonids. Experiment 1 was conducted on coho salmon and experiment 2 was conducted on steelhead. Coho salmon and steelhead were from the Washington Department of Fish and Wildlife (WDFW) Big Creek hatchery. Eggs were transported from Big Creek hatchery to AFT Center. For both experiments, juveniles 100 – 150 mm FL were anesthetized with 25 ppm clove oil. Each individual was measured for FL and weight and randomly assigned to one of 4 treatment groups. The treatment groups were control (fish were handled and adipose fin clipped), 12 mm PIT tag (fish were handled and surgically tagged with a 12 mm PIT tag), 20 mm PIT tag (fish were handled and surgically tagged with a 20 mm PIT tag), and 23 mm PIT tag (fish were handled and surgically tagged with a 23 mm PIT tag). Equal numbers of each treatment group were placed into 3 replicate 1.2 m diameter circular tanks with approximately 1 l/min well water at ambient temperature (12 ^{o}C). Fish were fed Bio-Oregon dry pellets daily at 1% body weight. Tanks were examined daily for tag loss and fish mortality. Fish were re-examined (anesthetized, measured, and weighed) 4 or 5 subsequent times to determine growth rates.

Experiment 2: Coho

Coho salmon were handled and tagged on 27 July 2001. A total of 207 fish were PIT tagged (69 per tag group) and 69 were handled as control fish. Fish were sampled (anesthetized, PIT tag interrogated, measured for FL and weight) again on 13 August, 21 September, 5 November, 17 December 2001, and 13 March 2002.

To examine whether tagging had an effect on the process of smolting, fish were subjected to 24 h seawater challenges to determine how well they tolerated the transfer. The first challenge was conducted on 13 March 2002. Fish from each tank were anesthetized, measured for FL and weight, and PIT tag interrogated. Fish were separated into treatment groups (control, 12 mm, 20 mm, and 23 mm) and every third fish from each group was transferred from freshwater to 33 ppt saltwater. Fish were kept in saltwater for 24 h at which time they were anesthetized, PIT tag interrogated, gill biopsies were taken for analysis of gill Na^{+},K^{+}-ATPase activity, and a blood sample was drawn for later determination of plasma osmolality. The second seawater challenge was conducted on 10 April 2002. Fish were separated as above and every second fish was transferred to seawater and sampled as above. On 8 May the final seawater challenge was conducted, the remaining fish were transferred to seawater.

Experiment 3: Steelhead

Steelhead were handled and tagged on 17 January 2002. A total of 225 fish were PIT tagged (75 per tag group) and 75 were handled as controls. Fish were sampled (anesthetized, PIT tag interrogated, and measured for FL and weight) again on 21 March, 2 May, 14 June, and 25 July.

Statistics

Tag retention was calculated for all tagged fish and each individual tag treatment as 100 times the number of fish retaining tags divided by the total number of fish tagged or tagged with each tag type. Survival was calculated for the same groups as 100 times the number of fish alive in a group at tagging divided by the total number in the group at the beginning of the study. Growth rates were determined between all sampling periods by calculating specific growth (Busacker et al. 1990). Three-way factorial ANOVA was used to compare length, weight, and growth rate for all groups. The three factors considered were date, tank, and tag size. In all cases the data were not normally distributed and were log transformed before running statistical analyses. Growth rate comparisons included only tagged fish because individual growth rates on control fish could not be calculated since they were not individually marked.

Results:

Experiment 2: Coho

Tag retention for all tag groups was 100%. A total of 207 fish were tagged and all 207 fish retained their tags. Overall survival was 98.5 %, 203 fish survived through the study. Four control fish, zero 12mm tagged fish, one 20mm tagged fish, and two 23mm tagged fish died before the study was completed. All fish that died during experimentation retained their tags.

TABLE 1. Length and weight (mean ± SE) at PIT tagging of coho salmon examined for effects of tagging on growth and smolting.

Treatment	FL – mm	Weight – g
Control	135.2 ± 1.24	34.0 ± 0.82
12 mm	132.3 ± 1.58	32.4 ± 1.04
20 mm	131.7 ± 1.47	31.9 ± 1.00
23 mm	132.4 ± 1.72	32.3 ± 1.09

Fish in all treatment groups grew throughout the experiment (Figures 3-7). The combined effects of time and tank on length and weight resulted in significant overall effects on fish (3-way ANOVA, $p < 0.0001$ for both). Size significantly increased over time (Time effect in 3-way ANOVA, $p < 0.0001$ for both), where length and weight were significantly greater at each successive sampling except for between periods one and two. The effect of tag size on fish size was not significant ($p = 0.06$ and $p = 0.0921$ for length and weight, respectively). There was a tank effect (Tank effect in 3-way ANOVA, $p < 0.0001$) for both length and weight, where all fish in one tank were larger than those in one other tank. There were significant tank*tag size ($p = 0.0001$) and time*tank*tag size interactions ($p < 0.0001$) for both length and weight.

Size within each time period did not differ among tag groups ($p < 0.05$). Tank effects were evident. All fish in one of the tanks were significantly smaller than all fish in one other tank, and the third tank had intermediate sized fish. In particular, the 12 mm and 23 mm PIT tagged fish in the "smaller" tank were smaller than control and 12 mm PIT tagged fish in the larger tank. These differences were maintained throughout the experiment. Within tanks there was only one significant difference between tag groups: on 21 September control fish were significantly larger than fish tagged with 23 mm tags.

FIGURE 3. Coho salmon fork length over time for control fish and fish tagged with 3 different sized PIT tags. Values are reported as mean and standard error. There were no significant differences within time periods for tag size.

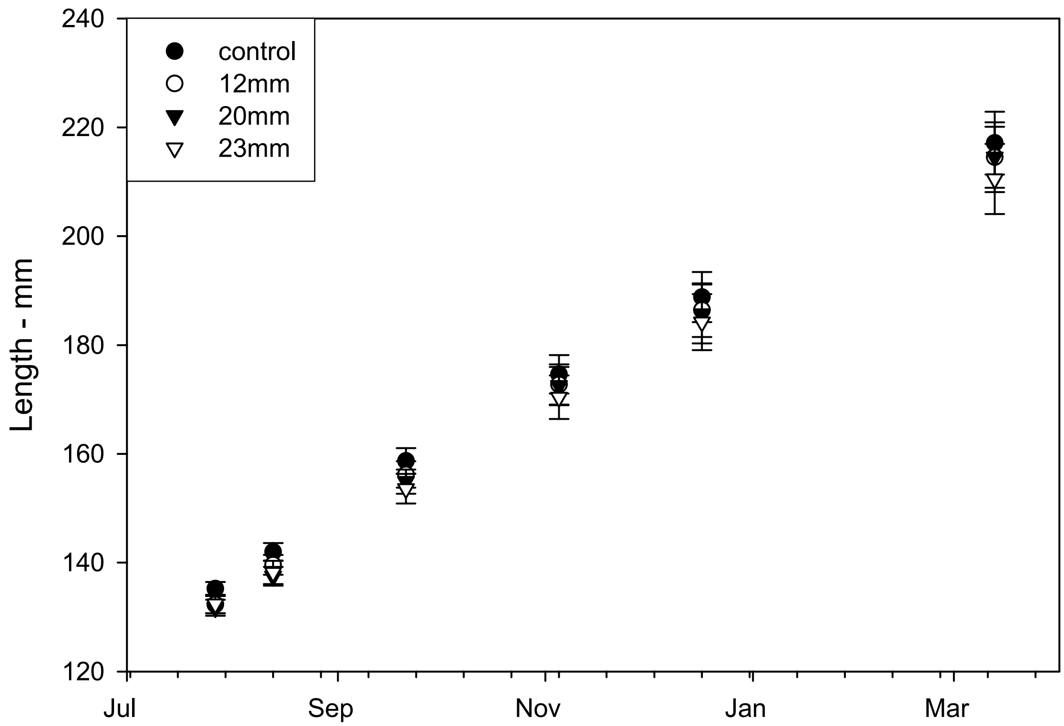
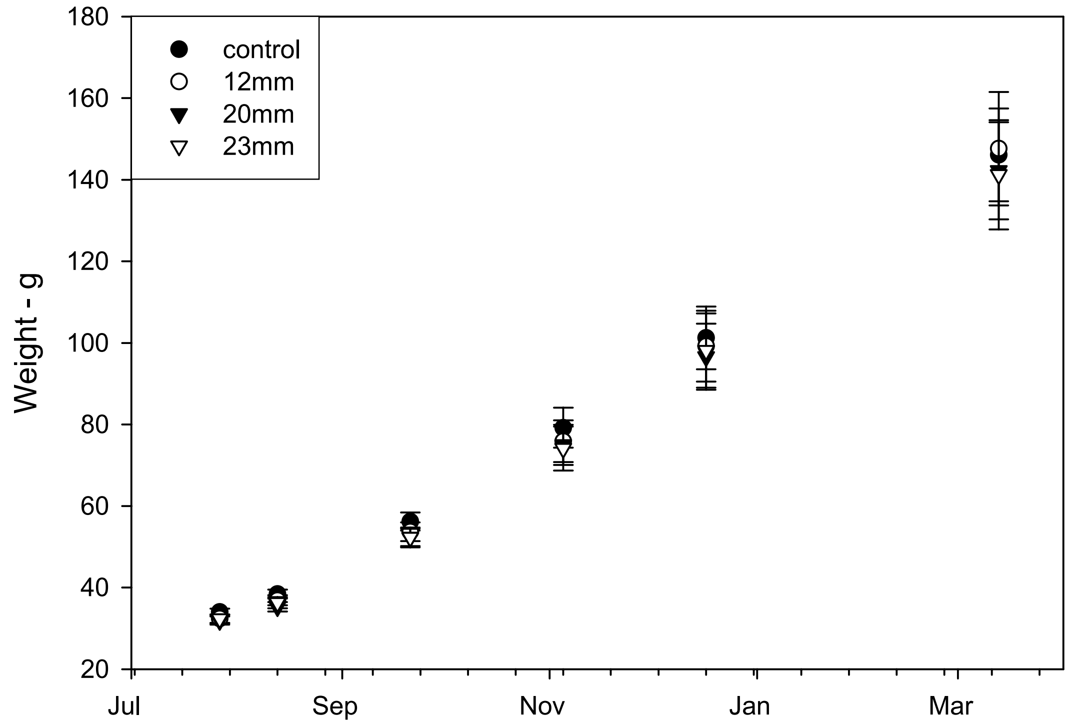
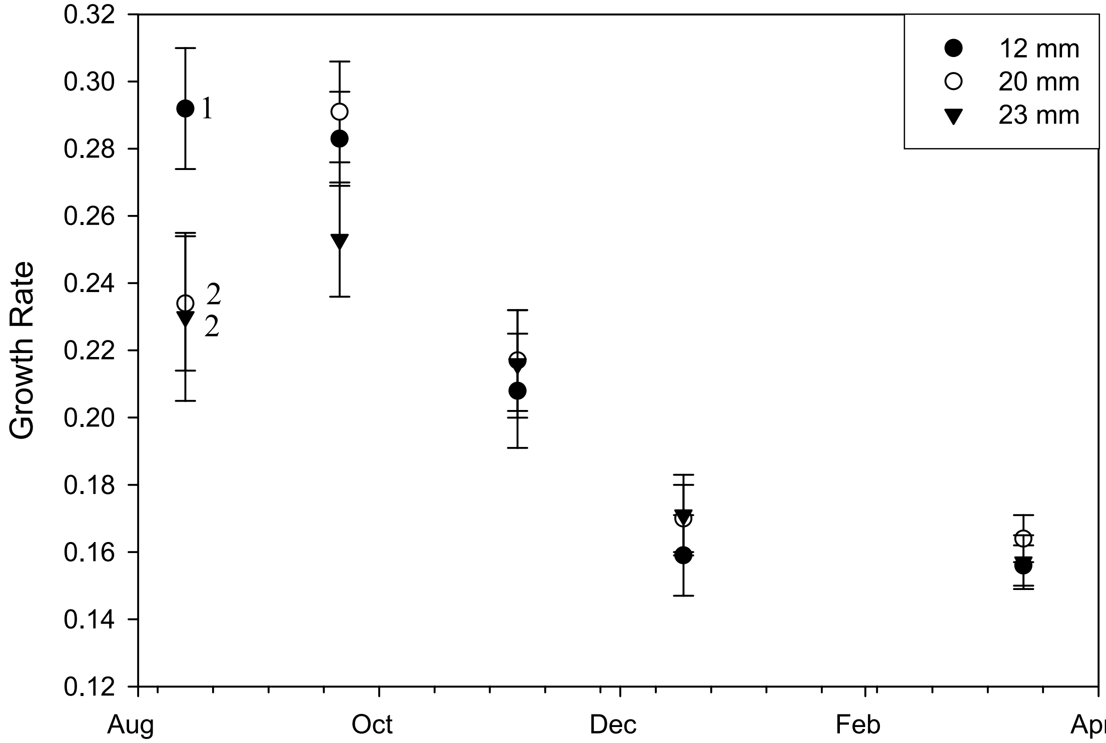


FIGURE 4. Coho salmon weight over time for control fish and fish tagged with 3 different sized PIT tags. Values are reported as mean and standard error. There were no significant differences within time periods for different tag sizes.



Individual growth rate for both length and weight (Figure 5) significantly changed over time, hence the resulting significant ANOVA (3-way ANOVA, $p < 0.0001$). There was no tank effect (3-way ANOVA tank effect, $p = 0.2349$ and $p = 0.3093$ and there was no effect of tag size on overall growth (3-way ANOVA, tag effect, $p = 0.3063$ and 0.7548) for length and weight. The individual growth rate during the first time period was significantly lower for the 20 mm and 23 mm tagged groups than for the 12 mm tagged group. During all other time periods, growth of all tag groups was the same. The only significant interaction effect was for growth in length for time*tank*tag size ($p = 0.0061$)

FIGURE 5. Coho salmon individual specific growth rate (%, body weight) over time for fish tagged with three different sized PIT tags. Values are mean and standard error. Different numbers next to symbols indicate statistically significant differences ($p < 0.05$) within that time period.



Mean growth rates (in length and weight, Figures 6 and 7) for control fish were intermediate compared to the tagged groups. Fish tagged with 12 mm PIT tags had the highest growth rate during the first time period with control fish intermediate between that value and growth rates for fish tagged with 20 mm and 23 mm PIT tags. During time periods 2 – 5 growth rates between tag groups became similar and overlapped by the end of the study.

FIGURE 6. Specific growth rate (% mm d^{-1}) for all tag groups displayed as mean values. Values are indicated without error because control fish were not marked as individuals.

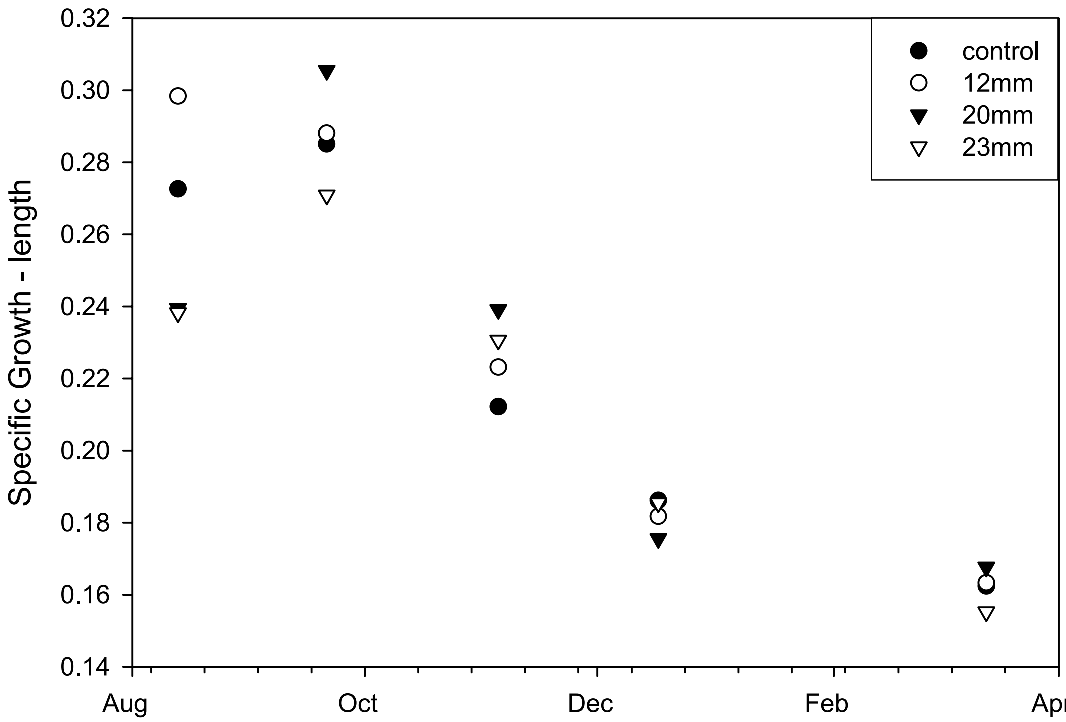
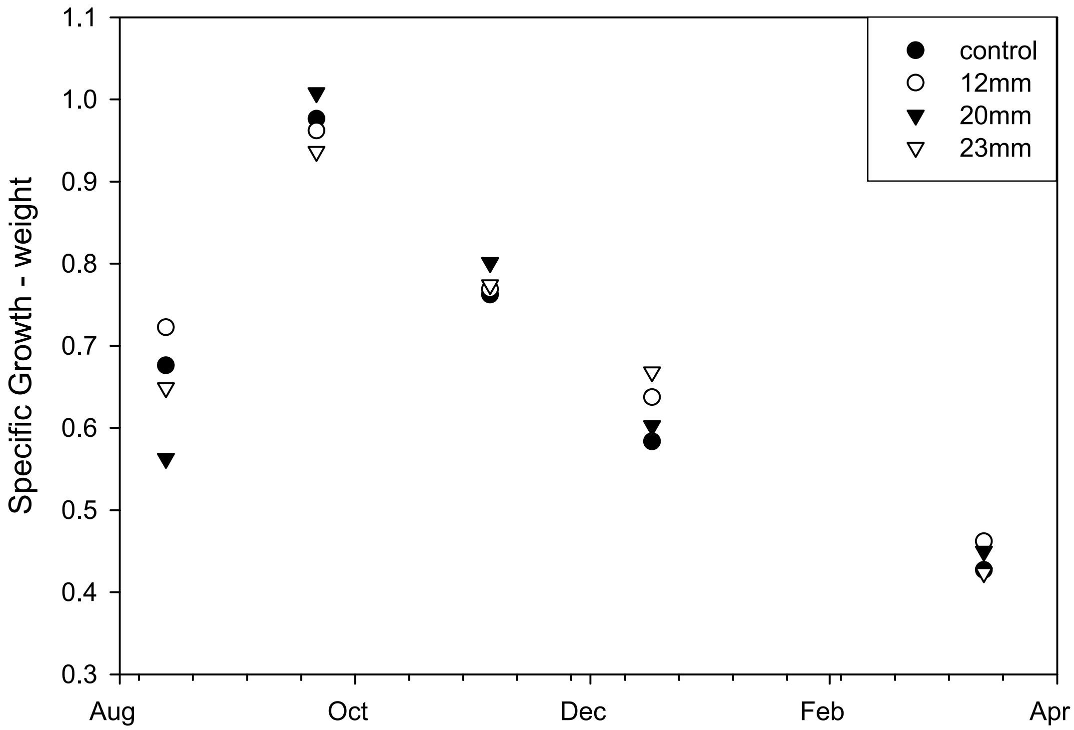
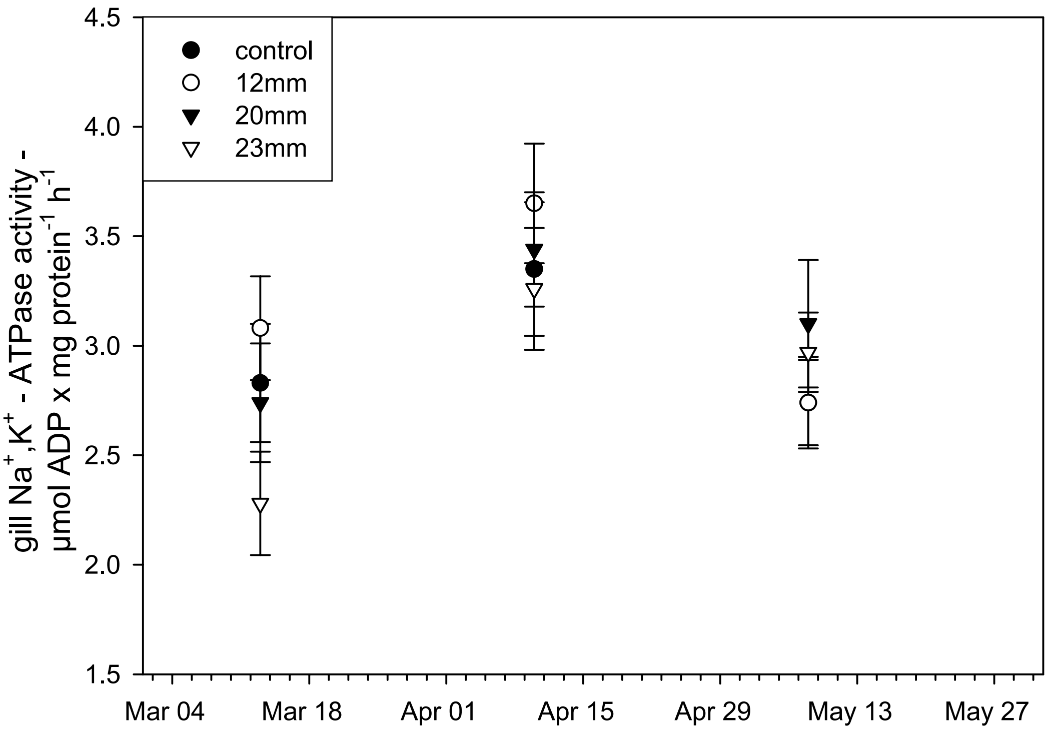


FIGURE 7. Specific growth rate (% g d^{-1}) for all tag groups displayed as mean values. Values are indicated without error because control fish were not marked as individuals.



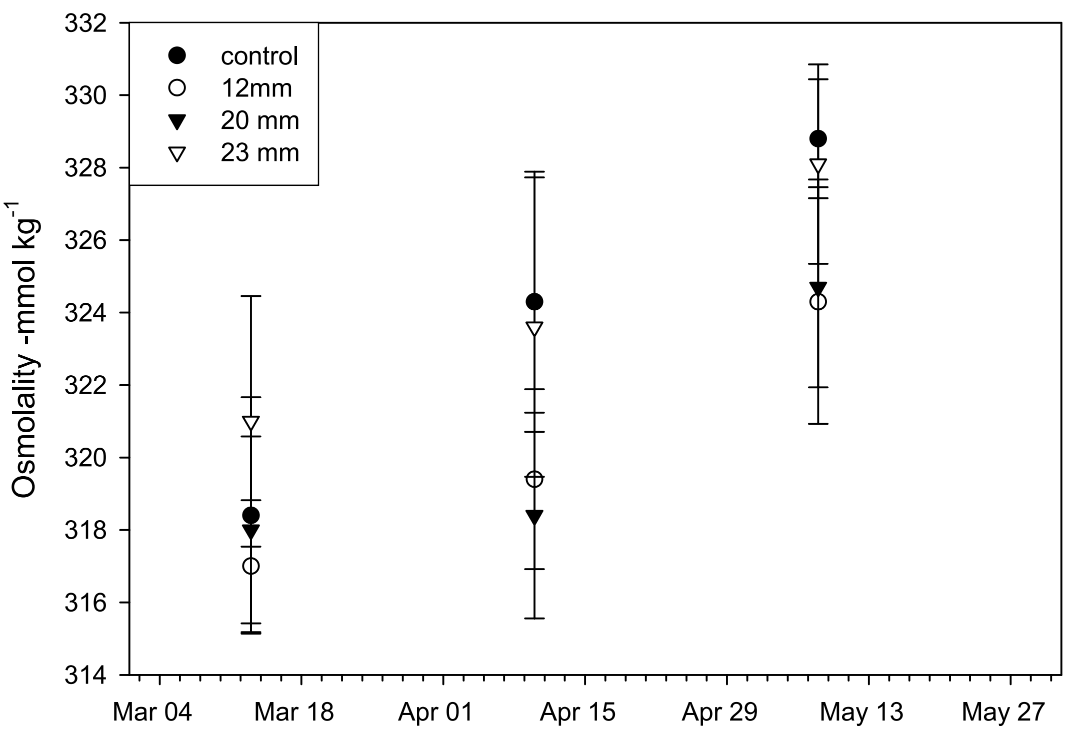
All fish subjected to 24 h seawater challenges survived. Gill Na^{+},K^{+}-ATPase activity (µmol ADP x mg protein $^{-1}$ h^{-1}) peaked during the second seawater challenge (Figure 8). The overall model for time, tank, and tag size effects on ATPase activity was significant ($p = 0.0369$). This difference was explained by time ($p = 0.0039$), where ATPase levels were highest at time period 2 and the same at periods one and three. Tank effects were insignificant ($p = 0.1455$). Tag size and all interaction effects were insignificant ($p = 0.2847$ and $p > 0.500$).

FIGURE 8. Gill Na^+,K^+-ATPase activity (µmol ADP x mg protein $^{-1}$ h^{-1}) of coho salmon juveniles subjected to 24 h seawater challenges. Data are expressed as mean ± SE. Different numbers next to symbols indicate statistically significant differences ($p < 0.05$) within that time period.



Plasma osmolality (mmol kg^{-1}) of seawater challenged fish progressively increased over time (Figure 9). The overall model for effects of time, tank, and tag size on plasma osmolality was significant ($p < 0.0001$). This difference was explained by tank ($p < 0.0001$) and time ($p = 0.0002$) differences where osmolality was greatest in the last time period and least in the first with all values being different from one another. Tag size and interaction effects were insignificant ($p = 0.1639$ and $p > 0.900$, respectively). Within each seawater challenge there were no differences in plasma osmolality for the different treatment groups.

FIGURE 9. Plasma osmolality (mmol kg^{-1}) of coho salmon juveniles subjected to 24 h seawater challenges. Data are expressed as mean ± SE. There were no statistically significant differences within time periods.



Experiment 3: Steelhead

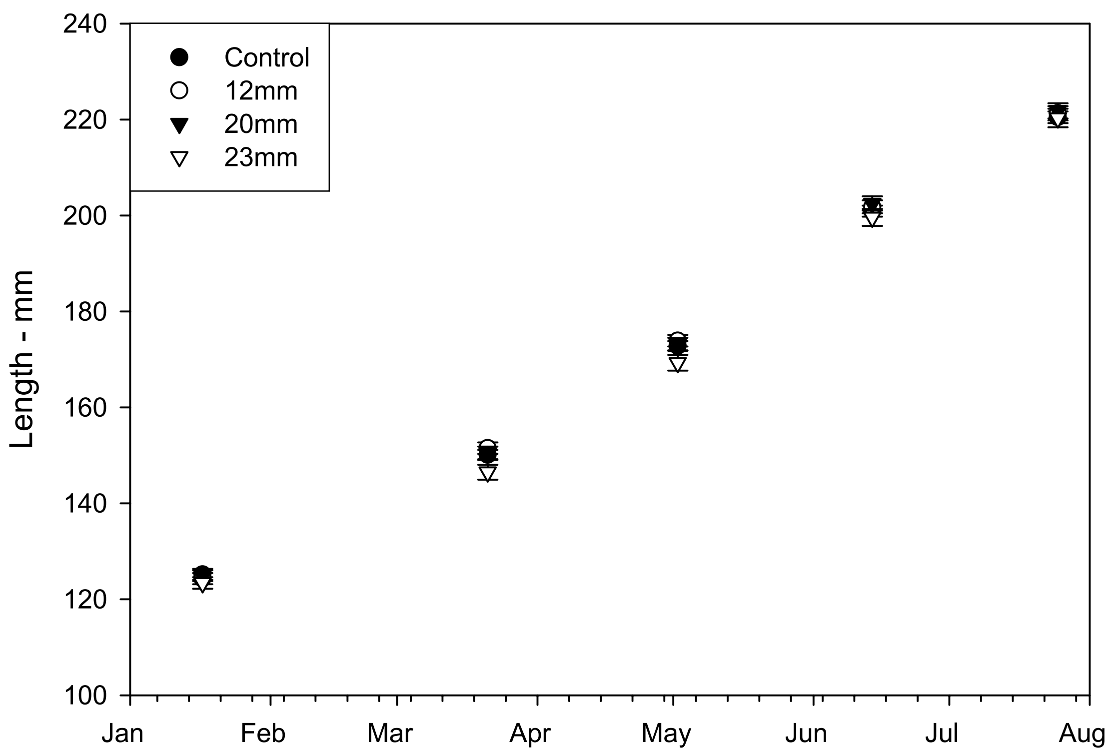
Tag retention for all tag groups was 95.0%. A total of 221 fish were tagged and 210 fish retained their tags. Tag retention for 12 mm, 20 mm, and 23 mm tags was 98.7%, 97.3%, and 89%, respectively. Overall survival was 98.6%, 217 fish survived through the study. One control fish, one 12mm tagged fish, zero 20mm tagged fish, and one 23mm tagged fish died before the study was completed. All fish that died during experimentation retained their tags.

TABLE 2. Length and weight, mean ± SE, at PIT tagging of steelhead trout used to examine the effects of PIT tagging on growth.

Treatment	Fork Length – mm	Weight – g
Control	125.2 ± 1.15	20.6 ± 0.61
12 mm	124.3 ± 1.17	20.0 ± 0.59
20 mm	124.9 ± 1.11	20.7 ± 0.60
23 mm	123.4 ± 1.20	20.5 ± 0.64

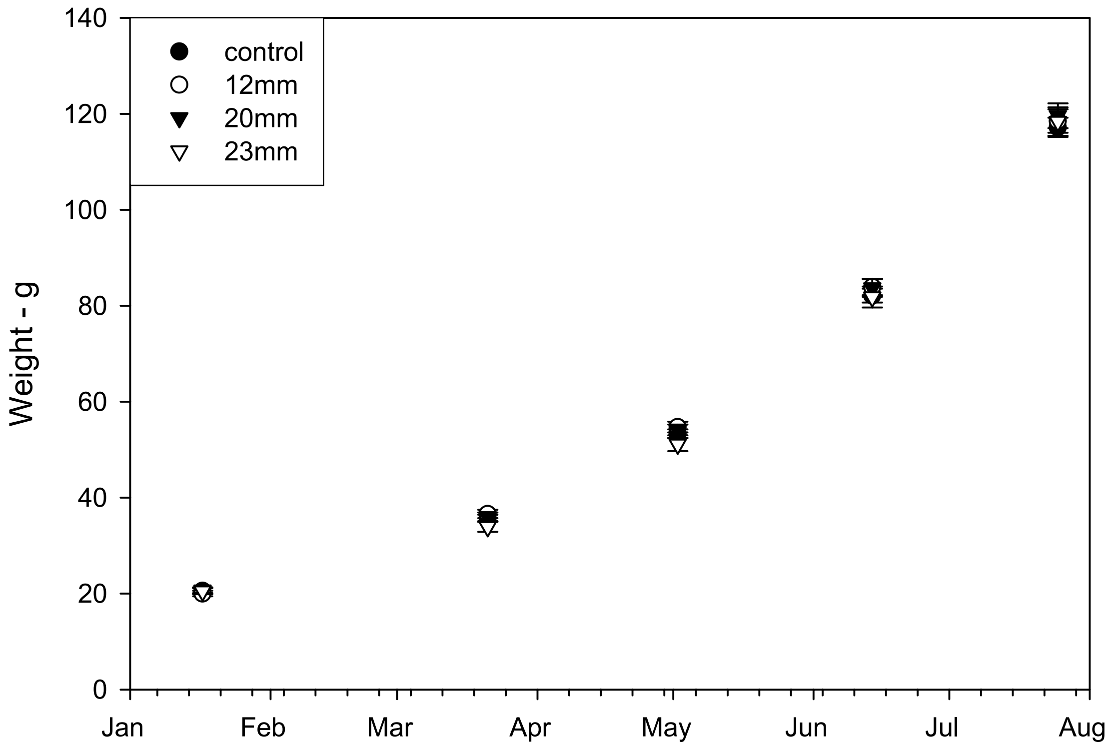
Fish in all treatment groups grew throughout the experiment (Figures 10-15). The combined effects of time and tag on fork length were significant (3-way ANOVA, $p < 0.0001$). Effect of time was much greater ($p < 0.0001$) than the effect of tag size ($p = 0.0021$). There was no tank effect observed for length ($p = 0.0609$). Length increased significantly over time where all time periods were dignificantly different from one another (Figure 10). Fish tagged with 23 mm PIT tags were tagged at a smaller size than all other tag groups and were significantly smaller than other groups throughout most of the experiment. There was a significant tank*tag size interaction ($p = 0.0230$) but no other significant interactions.

FIGURE 10. Steelhead trout fork length taken over time for control fish and fish tagged with 3 different sized PIT tags. Values are reported as mean and standard error. There were no differences in January, June or July. However, in both March and May 23mm PIT tagged fish were significantly smaller than all other tag groups ($p < 0.05$).



The effect of time resulted in a significant overall effects on fish weight (3-way ANOVA, $p < 0.0001$). Weight changed significantly over time (Time effect in 3-way ANOVA, $p < 0.0001$), where weight was significantly greater at each successive sampling (multiple comparison for each date, $p < 0.05$, Figure 11). There were no effects of tank or tag size on weight (3-way ANOVA, tank and tag size effects, $p = 0.3292$ and $p = 0.0690$). There were no interactions between effects ($p > 0.1102$).

FIGURE 11. Steelhead trout weight measurements taken over time for control fish and fish tagged with 3 different sized PIT tags. Values are reported as mean and standard error. There were no differences in January, July, and August. However, in March fish tagged with 23 mm PIT tags were significantly smaller than fish tagged with 12 and 20 mm tags. In May 23mm PIT tagged fish were significantly smaller than fish tagged with 12 mm tags.



Growth rate for both length and weight (Figures 12 and 13) significantly changed over time, hence the resulting significant ANOVA (3-way ANOVA, $p < 0.0001$). There was no tank effect (3-way ANOVA tank effect, $p = 0.3384$ and $p = 0.3448$ for length and weight). There was no effect of tag size on overall growth (3-way ANOVA, tag effect, $p = 0.8772$ and 0.8106 for length and weight). When examining within each time period growth from tagging to first re-sampling (63 d later) was lowest for the 23mm tagged group, intermediate for the 20 mm tag group and highest for the 12mm tag group. During growth periods 2 (March to May) and 4 (June to July) growth rate of all tag groups was the same. During growth period 3 (May to June) fish PIT tagged with 23 mm tags grew fastest ($p <0.05$). The only significant interaction effect was for growth in length for time*tag size ($p < 0.0001$).

FIGURE 12. Steelhead trout individual growth rates (in length) over time for fish tagged with three different sized PIT tags. Values are mean and standard error. Different numbers next to symbols indicate statistically significant differences within that time period.

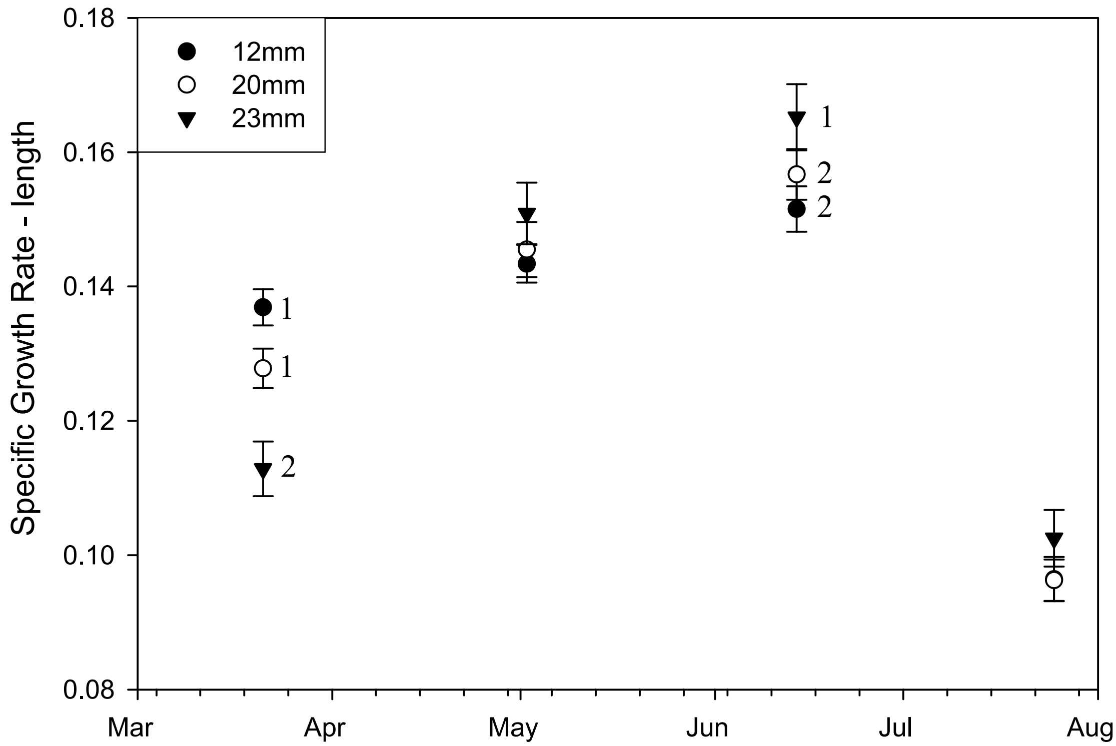
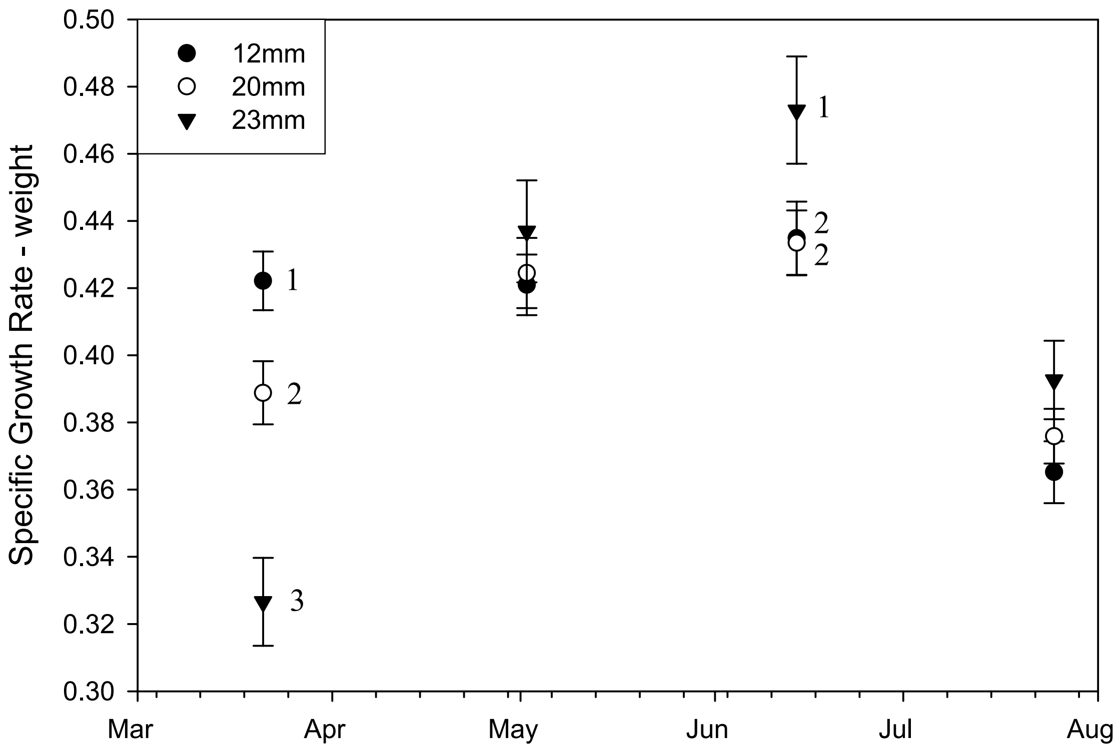


FIGURE 13. Steelhead trout individual growth rates (in weight) over time for fish tagged with three different sized PIT tags. Values are mean and standard error. Different numbers next to symbols indicate statistically significant differences within that time period.



Mean growth rates (in length and weight, Figs. 14 and 15) for control fish were similar to fish tagged with 20 mm PIT tags and intermediate compared to the 12 mm and 23 mm PIT tagged groups. Fish tagged with 12 mm PIT tags had the highest growth rate during the first time period with control fish intermediate between that value and growth rates for fish tagged with 20 mm and 23 mm PIT tags. During time periods 2 – 4 growth rates between tag groups became similar and overlapped by the end of the study. Growth rates for the 23 mm PIT tagged group were higher during the last two time periods than for the other time periods.

FIGURE 14. Specific growth rate in length for steelhead trout tagged with 3 different sized PIT tags, displayed as mean values. Values are indicated without error because control fish were not marked as individuals.

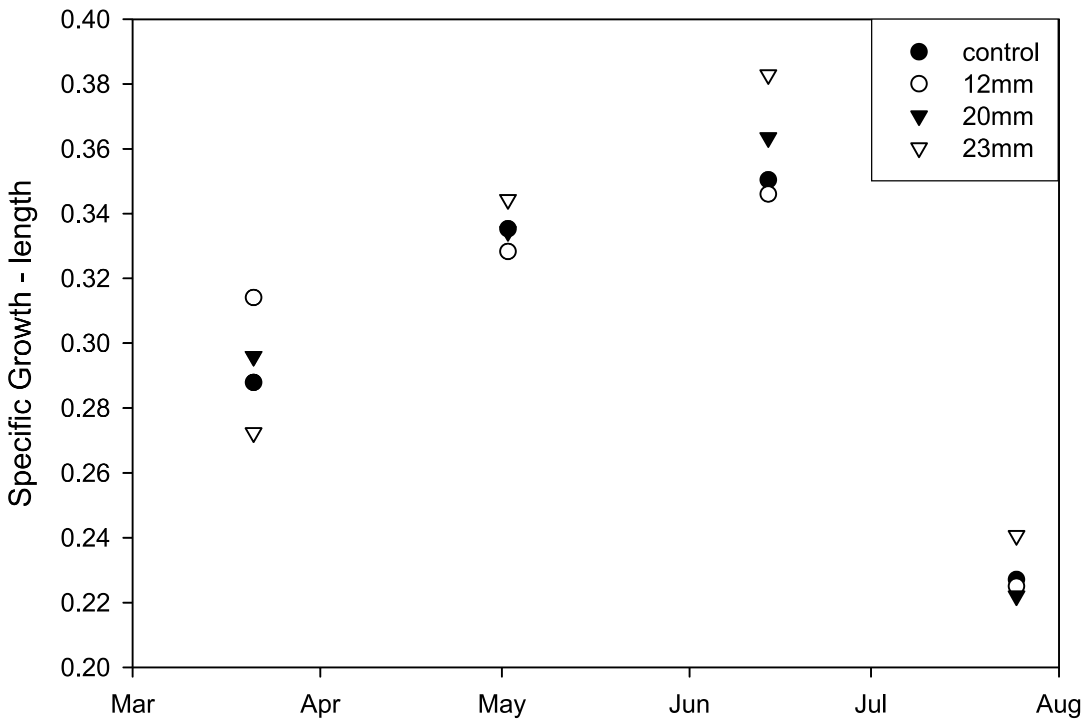
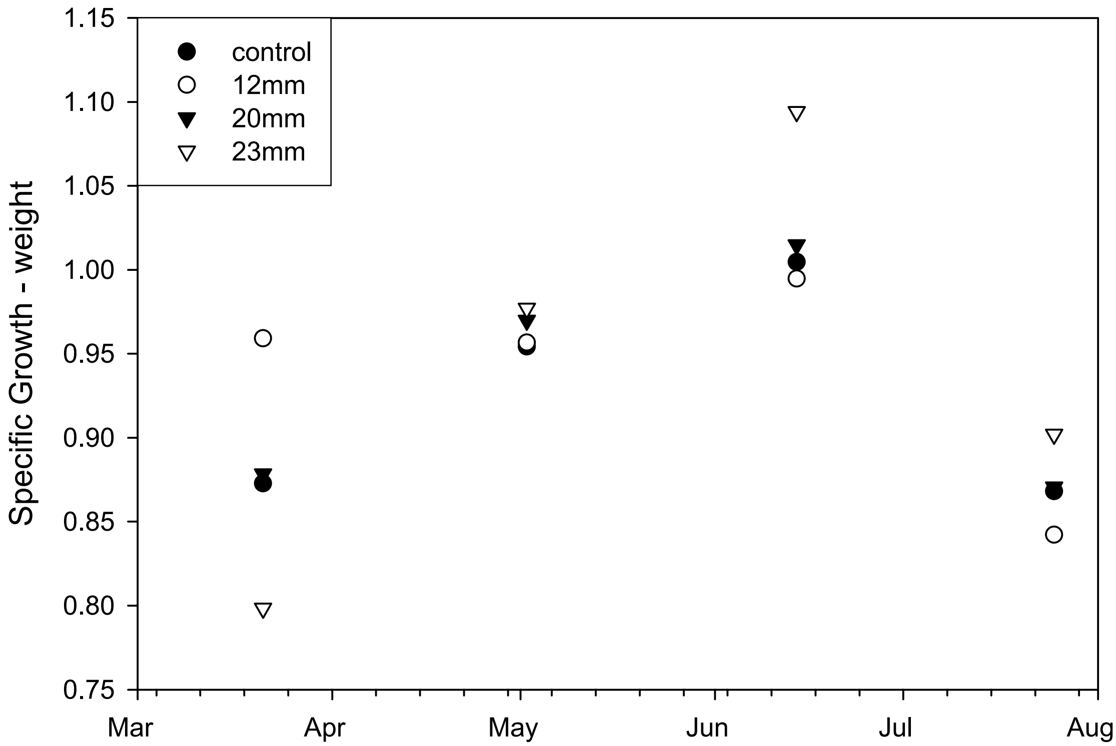


FIGURE 15. Specific growth rate in weight for steelhead trout tagged with 3 different sized PIT tags, displayed as mean values. Values are indicated without error because control fish were not marked as individuals.



Discussion:

Retention rates of field-tagged steelhead trout were high, 98%. This test verifies that laboratory and field applications using 23 mm PIT tags are relatively reliable. The rate of tag loss we observed is similar to others who have reported PIT tag retention/loss rates, primarily for 12 mm PIT tags, 2.3 – 5% loss (Ombredane et al. 1998, Juanes et al. 2000, Bell et al. 2001, Gries and Letcher 2002). Survival for the naturally produced fish returned to the laboratory was relatively low, in fact even lower for untagged fish than tagged fish. While this survival rate cannot be explained by disease it was likely caused by the difficulty associated with getting fish captured in the wild to feed once returned to the laboratory. Most of the fish that died were very thin and had no food in their digestive tract. Within the first week of entering the laboratory it was noticed that many fish were not feeding. Fish were put on various diets including coating fish feed pellets with krill oil to eventually feeding chunks of beef liver, but some fish never started feeding. Those fish that survived until the end of the study were those that were successful feeders.

Retention rates of 23 mm PIT tags surgically implanted in hatchery-produced coho salmon were 100%. This was extremely high and the same as that seen for coho PIT tagged with both 12 mm and 20 mm PIT tags. Furthermore, survival of coho PIT tagged with 23 mm tags (97%) was higher than for fish that were never PIT tagged (control, 94%). There was no effect of tag size on size of fish over the 6 month study period. Furthermore, it seems that choice of tank placement in a laboratory or hatchery would have more effect on individual fish size than PIT tagging alone (tank effects were significant while tag effects were not). These differences are not evident in the growth rates of individuals. Although there was no overall effect of tag size on growth rates there was a difference in growth rate from time period one to time period two for fish tagged with different sized tags. Fish tagged with 12 mm tag seemed to grow faster during this time period, perhaps making up for possible physiological effects that occurred immediately after tagging. This compensation in growth probably occurred in the other tag groups during the time between sampling since all groups were the same size and had the same growth rates at the end of the experiment (7 months after tagging).

Hatchery reared steelhead had a tag retention rate of 95%. Retention rate for 23 mm tags was somewhat lower, 89%. However, survival in all groups was high with that for 23 mm tagged fish being the same as the control fish, 99%. There was a tag size effect observed for length but not weight. This difference is easily explained by the discrepancy in length at tagging for the different groups. Growth effects within the first few weeks of tagging may or may not be consequential. However, all fish were the same size at the end of the experiment (6 months). These results were similar to those found by Ombredane et al. (1998) for brown trout, 7 months after tagging they were the same size as their non-tagged counterparts. Interestingly, although there were no effects of tag size on growth, growth compensation, likely due to the tagging event, is again observed for the 12 mm and 20 mm groups between sampling periods one and two. The compensation is then also seen for the 23 mm tag group between periods 2 and 3, where fish tagged with 23 mm tags have the highest growth rate and then all fish have equal rates at the end of the experiment.

While steelhead tag retention rates reported for naturally reared juveniles in this study were 98% those reported from laboratory experiments were generally lower. Both experiments closely emulated steelhead size for those that would be tagged in the field in the Fall. Therefore, we conservatively estimate tag loss in juvenile steelhead > 100 mm FL to be 95%. Coho salmon tag retention was 100%, but coho size at tagging slightly higher than those collected in Abernathy Creek in the Spring (Section II). Therefore, retention rates may be different for smaller fish, but even the smaller fish tagged in the study, 99 – 110 mm (n = 25 of 207), had a 100% retention rate.

There were no obvious effects of PIT tagging on smolting of coho salmon. The tagging event occurred in the Fall before smolting occurred. Therefore the effects on smolting were likely to be minimal or non-existent. The values reported for gill Na^+,K^+ ATPase activity and plasma osmolality fit well within those reported for other salmonids reared under hatchery conditions (Hoar 1988; Zydlewski et al. in press).

This is the first detailed report of PIT tagging effects on growth. All other studies report effects on tag retention and survival and rarely report growth. Ombredane et al. (1998)

reported no growth effects 7 months after PIT tagging brown trout with 12 mm tags. However, the same growth compensation effects reported here have been observed in cutthroat trout (J. Zydlewski, pers. Comm.) where a significant difference in size was observed at 14 and 28 d but by week 8 size was the same for control and 23mm tag groups. These data indicate that 23 mm PIT tag can be used with the same confidence as 12mm and 20 mm PIT tags without substantial negative impact on size and growth of individual cutthroat trout, steelhead trout, and coho salmon.

Conclusions

Implementation of SPIs allows accurate estimation of population characteristics. High efficiency and predictability of SPIs provides more accurate estimates of fish movement, migration patterns and population abundance than has been available previously. Life history characteristics determined for steelhead and cutthroat in Abernathy Creek exceed those more commonly measured with standard techniques. Migration timing and population estimates were similar for SPIs and screwtrap with higher efficiency using SPIs (97% vs. 22% with the screwtrap). Further, the SPIs allowed determination of year-round migratory patterns, daily migration patterns, travel time, and proportion of fish leaving different sections of the tributary.

SPIs allow monitoring of bank full width in small streams. Streamwidth monitoring is dependent on choosing appropriate sections of the tributary for installation. In this study SPIs were constructed in confined reaches (bridges) of a third order tributary, effectively monitoring 100% of the stream. Streamwidth monitoring is a very powerful tool when only a portion of a population is tagged and is being used to represent the whole population. However, SPIs are not restricted from use in open areas but alternate applications need to consider and report the proportion of tributary monitored.

The use of 23 mm PIT tags provides wide application of monitoring techniques for fish as small as 100 mm. While 23 mm PIT tags are larger than those applied in hatcheries (12 mm) their detectability in the field supersedes that of 12 mm tags. Antenna construction for pass-through detection of 12 mm tags is limited to an area of approximately 1.2 m^2, while the area covered by an antenna optimized for detection of a 23 mm tag is greater than 7.2 m^2 (a 5-fold difference). For applications where the goal is to monitor the entire stream (i.e. antenna size is important) the benefit of increased monitoring possibilities far outweighs the drawback of a larger tag. In recent years researchers have identified the need for assessing life history characteristics of smaller (or younger) fish. While still an important need, few researchers appreciated the possibilities and advantages of larger tags. Most importantly, while PIT tags applied in this study are larger (23 mm x 3.4 mm, 0.6 g) than the 12 mm PIT tags (12 mm x 2.2 mm, 0.09 g) they are considerably smaller and last infinitely longer (infinite tag life since there is no battery) than radio tags (20 mm x 8.8 mm, 1.7 g, 45 d life) used to monitor natural migrations of both hatchery and wild fishes.

Portable detection systems developed and evaluated in this study allow for location of tagged fish, resident or migratory. This allows exact location information for fish that do not move with high water events or at the end of a predicted migration. The backpack system is already being used to determine habitat choices of hatchery- and naturally-reared steelhead trout. It will also be used to identify released hatchery fish that residualize in tributaries. Furthermore, by identifying micro and macrohabitat choices, individual and population level habitat information can be further linked to land use practices including habitat restoration projects.

SPIs will allow long term monitoring of smolt to adult return. This long term regimen can be applied as a highly efficient method to supplement or replace more standard methods like smolt and adult trapping. Because PIT tags have an infinite life when adults PIT tagged in streams return through the SPIs they will be identified and numerous aspects of their juvenile characteristics can be tracked to the adult return time. Also, adult escapement of multiple species can be determined without capturing the adults themselves. The combination of pass-through stationary and portable systems reduce the need to rely on smolt traps for smolt recruitment information, provide a more reliable technique for monitoring stream movements of PIT tagged fish, and decrease the need for using radio telemetry in small streams.

This project has developed a suite of tools which can be used effectively in tributaries within and without the Columbia River Basin. These tools will prove invaluable for monitoring fish populations in areas where it was not possible before. SPIs offer a cost effective and highly accurate method for collecting data required for making pivotal fish management decisions in a time when these decisions are carefully scrutinized.

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